PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	
Andrew CHEPAITIS	Confirmation No.: 6278
Application No. 10/511,036	TC/Art Unit: 3714
Filed: October 13, 2004	Examiner: Nikolai Gishnock
For: DYNAMIC TACTILE AND LOW VISION FONTS	Atty Docket: P66690US1

DECLARATION UNDER 37 CFR § 1.132

Mail Stop AMENDMENT
Commissioner for Patents
PO Box 1450
Alexandria, VA 22313-1450

Sir:

I, ANDREW CHEPAITIS, declare that:

1. I am the inventor of this application.

2. I have read and I understand the Office Action dated August 16, 2007 and the references cited therein.

3. My qualifications as a person of skill in the art are set forth in the resume attached to this Declaration. A copy of the article "Comparison of the ELIA and Braille Tactile Alphabets for Adults Visually Impaired Readers" listed in my resume also is attached to this Declaration.

4. The font described and claimed in this application resulted from research studies and from iterative testing and design between research studies. The result of the testing and

redesigns is an alphabet that is more tangible (defined as the ability to distinguish by touch) and that leverages existing technology to its full extent. In total, 25 of the 26 alphabetic symbols of the original font (as described in the Chepaitis '108 patent) have changed due to iterative, systematic testing and redesign. Each of the changes was the result of an analysis and evaluation of data from the research. Each alphabetic symbol evolved due to a series of research activities and informed design decisions.

5. The original configurations (Chepaitis '108) were generated based on well established ergonomic theory and human factors engineering principles that could be applied systematically to design a new tactile alphabet using a wide range of symbol configurations. For Chepaitis '108, Elia V. Chepaitis chose those configurations that made the most sense, according to the tenets of the field. However, the configurations were not based on applied research or known tactile acuity phenomena, nor did they leverage the technology of our current date. This was because, at the time of the original configurations, little was know about how tactile shapes other than Braille are identified, and no methods of producing continuous raised line tactile text were available. Indeed, in 1988 there were no viable means to accurately print the configurations from a computer printer. While the configurations of the original alphabetic symbols in Chepaitis '108 were improvements over existing art, they themselves could be improved. Our research and iterative design efforts refined these configurations to meet both the physiological needs and learning process needs of humans.

6. The iterative design process resulted in new alphabetic symbol configurations that require specific dynamic characteristics that could not have been predicted without extensive research and development. My team and I won over $520,000 in research grants, and over $400,000 in private investor funding to improve the past art. The research was carried out in

four research grants by a team of 24 researchers (including me) who trained and tested 204 subjects for as much as 60 hours each. The subjects learned, practiced and were tested with an ELIA® Tactile Alphabet font, the Braille alphabet or a raised Roman alphabet font. The subjects gave over 150,000 test responses. All subject testing errors were reviewed with the subject for training purposes, as well as to gather subjective information from reader about the alphabetic symbol configurations and training regime. End-of-study errors were compared within and across subject groups. New fonts were designed according to 1) the findings of the controlled research studies, and 2) the findings of research and development conducted between controlled research studies. The results of these efforts and the specific reasons supporting the redesigns are included in this document.

7. Given the current state of art at the date this application was filed and the extensive efforts that were required for me to develop font described and claimed in this application, it is highly unlikely that a person skilled in the art but who did not have access to the research data would have created the configurations and fonts described and claimed in the application. Additionally, few other research studies have been conducted on tactile reading and tactile font development and evaluation. As such, while the state of the art for visual text presentation (including the art described in Desrosiers, Jeffrey, Fujisawa et al., and Prince et al.) has improved , the tactile font tangibility needs of a tactile reader have not been similarly addressed.

8. *Development Strategy*: I employed a systematic development strategy to improve the original alphabet.

9. Through testing and subject feedback, the most and least tangible alphabetic symbols were identified. Those features that were most recognizable were incorporated into the

redesigns of the least tangible alphabetic symbols. For example, the original alphabetic symbol G was found to be very tangible, while the original alphabetic symbols M and W were found to be very difficult to differentiate from other alphabetic symbols. As such, I incorporated the G's configuration features into the configurations of the M and W, resulting in more tangible configurations for those alphabetic symbols (see Table 1 (attached to this Declaration), columns 3 and 8)

10. Alphabetic symbol redesigns were prioritized according to how frequently each alphabetic symbol is used in the English language. Alphabetic symbols of higher frequency were designed with the most tangible tactile element configurations that had been identified. For example, after the second study, the most frequently used alphabetic symbols - E, A, I and R - were all redesigned to improve their tangibility, even though they were not found to be the most tactilely difficult alphabetic symbols. As a result of these redesigns, the overall utility improved (see Table 1 columns 10 and 11 and explanation of utility measures in caption for this table (attached to this Declaration)).

11. Confusion matrixes were employed to identify how random the errors were for a given alphabetic symbol. The more random the errors the more poorly designed the alphabetic symbol was for tactile reading, as subjects could not make accurate educated guesses as to its true composition. Conversely, if the errors were concentrated, then the configurations could be improved and subjects could be practice specific alphabetic symbol exercises designed to improve their recognition rate with those alphabetic symbols. Researchers had previously constructed confusion matrices from tactile alphabetic symbol identification tests, but had not advanced the art beyond their tested configurations.

12. Each subject error was catalogued and the errors were analyzed to identify redesign opportunities. For example, the most common error in study #2 was when subjects mistakenly identified the alphabetic symbol "I" as the alphabetic symbol "S", or visa versa. This error accounted for 6% of all errors in our second study (see Table 2 (attached to this Declaration)). Furthermore, the most common 10 confusion errors (out of 390 possible errors) accounted for 34% of all errors. See Table 2 (attached to this Declaration). By redesigning these alphabetic symbols, substantial improvements were achieved. As illustrated in Table 2 and 8 (attached to this Declaration), during Study #3, after our major redesign of the alphabet, circle /square errors were no longer a common occurrence. Indeed, none of the top ten errors in the study #3 were circle /square confusions, and these new top ten errors occurred with the least frequently used alphabetic symbols.

13. Errors were categorized into four types of errors, 1) errors where the frame was correctly identified and the interior elements were incorrectly identified, 2) errors where the frame was incorrectly identified and the interior was correctly identified, 3) where both the frame and the interior elements were incorrectly identified and 4) where the frame was correctly identified and the interior elements were incorrectly identified due to orientation (for example an R for a D). Those errors where either the frame or the inside element was identified correctly were essential errors to analyze as they suggested what alphabetic symbol features subjects could feel. Orientation errors are most effectively addressed through changes to training and practice regimes.

14. Asymmetric confusion errors were reviewed. For example, in the initial study, the alphabetic symbol F is misidentified as the alphabetic symbol L with some frequency, but not visa versa. In study #2, the alphabetic symbols G, J, M and W were often confused with the

alphabetic symbol "I", but not visa versa. Additionally, the alphabetic symbol Q was often confused with the alphabetic symbol S, but not visa versa. Asymmetric errors were evidence that elements of the misidentified alphabetic symbol were identified as too similar to the interior elements of the more tangible alphabetic symbol. The less tangible alphabetic symbols were redesigned to address these errors.

15. Through experimentation, I identified that certain frame features were more recognizable than others, including the shapes of the frames. Several frame shapes were tested to identify the most tangible. See Table 3 (attached to this Declaration) for illustrations. The research studies generated analyzable data suggesting that the circular and square frames were not sufficiently different.

16. Font variables such as font size, inter symbol spacing, line width and interior element spacings were varied and tested to ascertain which configurations were most tangible. For example, at small font sizes the alphabetic symbol F was often misidentified as the alphabetic symbol L. This was because its interior line was in close proximity to the top of the frame. At larger font sizes, where the line spacing was greater, this misidentification did not occur.

17. *Study #1 Findings*:

18. The first study was a small pilot study with nine sighted subjects who were taught the new font visually and were then tested on their tactile reading skills while blindfolded. This study identified several flaws in the original design that could not have been anticipated prior to the research. Subject errors in both testing and training were tallied and feedback from them was gathered regarding the configurations of the alphabetic symbols.

19. The subject errors were useful for identifying which elements were tangible and not tangible. The most tangible 50% of the alphabetic symbols (D, E, F, G, H, I, L, N, O, P, Q, T, Z) all had significant open space and only one interior line. Many of the least tangible alphabetic symbols (A, B, C, J, K, M, R, S, U, V, W, X, Y) had more than one line, parallel or near parallel internal lines that were close to the frame, lines that were anchored to the frame in a corner, and/or tactilely felt identical. In the case of the S and R, the interior characteristics felt nearly identical, as their differentiating features required more spatial resolution than readers possess. Also, in the case of the F, it was found that its interior line was too close to the upper horizontal line of the frame; the H was ranked as the 15th least tangible alphabetic symbol, for similar reasons.

20. Errors were found to be non-random so they could be grouped, for example, as described in Table 4 (attached to this Declaration). Data could be analyzed according to these groupings and the alphabetic symbols could be redesigned to improve their tangibility.

21. 1) The capital frames were not identifiable – they substantially reduced the tangibility of the alphabetic symbols. The researchers found that when testing the alphabetic symbols, the accuracy rates for the capital alphabetic symbols were much lower than those for the lower case alphabetic symbols, even though the lower case alphabetic symbols were identical to the upper case alphabetic symbols, except for the additional exterior frame. As such, several different iterations of capital alphabetic symbol identifiers were tested. They included a half frame parallel to the left side of the alphabetic symbols, a single line parallel to the left hand side of the alphabetic symbols, multiple and single dots above and to the left side of the alphabetic symbols. The alternative parallel frames also reduced tangibility. The multiple dots, one to the left side of the frame and one above did not reduce tangibility but slowed down the reader

compared with the single dot above the alphabetic symbol, which was just as tangible, but took less time to identify.

22. 2) The alphabetic symbol C was most commonly confused with the alphabetic symbol O, but not visa versa. As the small dot in the alphabetic symbol I was easy to distinguish, the element in the C was changed to the Font #1 design (see Table 1 (attached to this Declaration)). This nearly eliminated C to O confusions. Further improvement in the C would come after the next research study.

23. 3) Where interior lines and exterior line intersect, readers have difficulty identifying the characteristics, features and configurations of the lines. For example, elements that were located in corners of a square frame were difficult to feel. In the initial study, this phenomenon was especially evident with the alphabetic symbols A, J, K, M, U, V, W, Y and X.

24. Other confusions were also evident, but the rate of these confusions dropped dramatically when the reader practiced. The above errors persisted, and as such, required redesign.

25. Subjects felt the G's with high accuracy while the alphabetic symbols M, W were difficult to feel. The J was also difficult to identify. As such, the M, W and J were redesigned to be nearly identical to the G. To achieve this, the shape of the G was rotated 90 degrees, 180 degrees and 270 degrees, respectively, to achieve new, more tangible alphabetic symbols. See Table 1 (attached to this Declaration) for the changes to these alphabetic symbols.

26. Also, the applicant discovered that readers have a difficult time identifying tactile shapes that are close to the frames, was an essential finding. This phenomenon was especially evident when tactile lines met the frames in the corners of the frames. It is extremely difficult to feel these elements of the original configurations. As such, the V, J and the K were altered. The

diagonal lines of the K and V were moved to near the middle of the frames. The final location of these lines on the frames was identified through additional testing. If the lines were too close to the far corners, they were less discernable, as they cluttered the open spaces within the frames (and readers identify alphabetic symbols in part by the shape of the open space in the alphabetic symbol). If the interior angel of the lines was too obtuse and therefore the lines met the frame too close to the near side of the frame (where the diagonal lines met), the space was too open and these symbols would often be confused with an L or H.

27. The alphabetic symbol S was often confused with the alphabetic symbol R, as the aggregate shape of the S is very similar to the R when reading them tactilely. Meanwhile, the I symbol was identified with high accuracy. As such, we put a dot in the S to make it more legible. I tested this shape and the R/S error rate dropped. Later, subjects stated that the two alphabetic symbols would be easier to differentiate if the swirl of the S was reduced. This was done and the error rate dropped.

28. *Alphabetic Symbol Review and Commentary*:

29. No changes were identified for 13 alphabetic symbols – B, D, E, I, L, N, O, P, Q, R, T, X, Z.

30. Information from the study led to the redesign of the following alphabetic symbols:

31. A – the bottom line was dropped as its inclusion added clutter and reduced tangibility. The angle of the two remaining lines was widened to create more open space inside of the alphabetic symbol.

32. C – The size and placement of the interior C changed. Upon finding that the C needed redesign and that the I was very tangible, the applicant redesigned the C to leverage the benefits of a small circular shape similar to that found in the I.

33. F – The interior line in the alphabetic symbol F was moved away from the top of the frame, as it was often misidentified as the alphabetic symbol L. This new spacing in the F made it more tangible. The space between the interior line and the top of the frame was identified as space that should change at a different rate than the size of the alphabetic symbol.

34. G –The interior line was reduced in size as the G was most often confused with the alphabetic symbol I.

35. H - The interior line in the alphabetic symbol F was moved away from the top of the frame. This made it more tangible. The space between the interior line and the top of the frame was identified as space that should change at a different rate than the size of the alphabetic symbol.

36. J – The interior element was moved out of the corner and up the left hand side

37. K – The original design for the alphabetic symbol V was found to be more tangible than the alphabetic symbol K. As such, the point at which the two diagonal lines meet was moved to the left side of the frame. Also the diagonal lines were moved away from the right hand corners, so that they could be more easily distinguished from the lines of the corner of the frame. This also changed the shape of the interior open space, so that it was more recognizable.

38. M – The diagonal lines were replaced with a single vertical line that would be less confused with other alphabetic symbols' interior elements. The subjects' success with the alphabetic symbol G drove this change.

39. S – the curved lines were reduced and a dot was added. This was an attempt to distinguish it from the alphabetic symbol R. Also, the alphabetic symbol "I" was found to be very tangible and a dot was not already used in a circular alphabetic symbol. We started with the symbol , which looks like the Chinese symbol for ying/yang, but found that just a dot was much more tangible.

40. U – The interior elements were modified to occupy a portion of the square frame that no other alphabetic symbol was utilizing.

41. V – The diagonal lines were moved away from the top corners of the frame, so that they could be more easily distinguished from the lines of the corner of the frame. This also changed the shape of the interior open space, so that it was more recognizable.

42. W - The diagonal lines were replaced with a single vertical line that would be less confused with other alphabetic symbols' interior elements. The subjects' success with the alphabetic symbol G drove this change.

43. Y – The single line it the corner was difficult to find and identify. Two lines originating from the corners were found to offer superior tangibility. As a result of additional research, this would later be changed to two dots.

44. *Study #2*:

45. *Overview and Design*:

46. Study # 2 was a controlled experiment that included 30 hours of training and testing of 100 subjects all over the age of 65. Over the course of the 30 hours of the study, they were blindfolded and taught one of three alphabets – the raised Roman alphabet, Braille or the ELIA® Alphabet. As a part of training and research, each subject testing error was reviewed by instructors with the subject (one-on-one). This generated subjective human factors information

on the nature of the errors. Final errors were aggregated into a confusion matrix so that common confusions could be measured with greater precision. Subjects in the Roman and ELIA® Alphabet groups were trained and tested at font sizes of 1.0 cm, 1.1 cm, 1.2 cm and 1.3 cm. Subjects in the Braille group studied and were tested at 0.6 cm, the font size for standard Braille. Subjects in the Braille group had great difficulty and were unable to learn the complete alphabet in 30 hours. See Chepaitis, et al, 2004, for greater detail.

47. This study was executed to measure reading speed and individual alphabetic symbol recognition speeds. It was not designed to identify and evaluate different font configurations. However, subjects read far more tactile materials than anticipated and useful confusion matrices were able to be constructed for alphabetic symbol by alphabetic symbol design comparisons and evaluations, though the number of responses per symbol of the alphabet were not near equal.

48. *Summary of Finding for Study #2:*

49. Tables 1, 2, 6 and 7 (attached to this Declaration) delineate the errors that occurred in the first clinical study (study #2). They are examples of how the researchers analyzed the data for each alphabet tested. The major tactile alphabet design findings from this study were that:

50. 1) The frame shape required innovative redesign. Readers would benefit from more tangible frame configurations for both the circular and square alphabetic symbols. New frame design features were identified through this research study.

51. 2) The spacing, size and placement of interior elements and alphabetic symbols affected performance.

52. Subjective information from the study included that subject read with different fingers when at the end of a line than at the beginning.

53. For example, in the Table 7 confusion matrix (attached to this Declaration), it is evident that in testing, while the subjects identified the alphabetic symbol "A" correctly 91% of the time, when the subjects incorrectly identify the alphabetic symbol A, they most often responded that it was either a C or an O. Indeed, more than half of all errors with respect to the alphabetic symbol A were a "C" or "O" response. This suggests that they had difficulty feeling the difference between the interior elements of the A, but were able to feel that there was significant open space and that the alphabetic symbol had a circular frame.

54. Another example of a common error was when a subject misidentified a alphabetic symbol "T" and instead identified it as a alphabetic symbol "D." While subjects identified the alphabetic symbol T with 95% accuracy, more than half of all errors occurred when the subjects responded "D" instead of "T". Evidently, subjects were often having difficulty differentiating the circle and square frames of the alphabetic symbols D and T. In this study, this type of error (circle/square) was especially common at font sizes that approached the tactile acuity thresholds of the subjects (i.e. the font size was too small for comfortable reading). Indeed, in the ELIA® Alphabet group, 17% of errors occurred when a subject correctly identified the interior elements of the alphabetic symbol and incorrectly identified the frame (See Table 7 for the confusion matrix of the study). We do not believe that someone schooled in the existing art would have predicted this. Also, it is unlikely that someone schooled in the art would have identified that the D in the ELIA® Alphabet would be substantially more tangible than the D in the Roman alphabet - due to the difficulty of subjects to identify the corners of

tactile frames. This conclusion would not have been obvious without a thorough review of the research results.

55. *Alphabetic Symbol Review and Commentary*:

56. All but one alphabetic symbol (the alphabetic symbol O) changed as a result of the findings of this research. Below is a list of the changes and the rationale. (see Study #3 for an accuracy comparison of the effects of the redesigns)

57. A – The alphabetic symbol A was mainly confused with the alphabetic symbols C and O, which, as mentioned above, suggesting that the subjects had difficulty differentiating the interior characteristics of the A and differences in the shapes of the alphabetic symbols' open spaces. These errors could be reduced by redesigning the frame to incorporate the features of the Roman alphabet C in a unique configuration. Yet its new design (see Table 1 (attached to this Declaration)) is still congruous with the other alphabetic symbols in its group (B, C and D).

58. B – The alphabetic symbol B was most often confused with the alphabetic symbol P, and this confusion was reduced between this study and study #3 (see Table 1 (attached to this Declaration)) by incorporating the frame elements of the Roman alphabet letter C, thereby differentiating its frame from that of the P.

59. C – By incorporating the frame of the Roman alphabet letter C, the ELIA® alphabetic symbol C became more tangible.

60. D – By incorporating the frame from the Roman alphabet letter C, the ELIA® alphabetic symbol D became more tangible. The D was most often confused with the alphabetic symbol T in Study #2. This error largely disappeared after the redesign.

61. E – The E was often misidentified as the alphabetic symbol P, and visa versa (24% of all E and P identification errors were between the two alphabetic symbols). By adding points to the corners of the frame of the E, it was made more tangible.

62. F – Points were added to the frame of the alphabetic symbol F. As it is and was most often misidentified as the alphabetic symbols E and L, its accuracy rate remained relatively constant across the two studies. However, the amount of space between the top of the frame and the interior line was found to affect tangibility, with a greater number of F/E errors coming at a large font size and a greater number of F/L errors occurring at the smallest font sizes. This suggests that the space should be adjusted according to font size. At large font sizes there should be less space between the interior line and the upper frame. Therefore, it is essential that this space change at a non constant rate with font size changes.

63. G – Points were added to the frame of the G. Additionally, because the G, J, M, Q and W were often misidentified as the I and S (or each other), the small lines inside the frames were shortened. Also, the lines were redesigned so that the side closest to the frame could be more tangible (i.e. its presence would not be blocked by the middle most edge of the interior line).

64. H - Points were added to the frame of the alphabetic symbol H. Its accuracy rate remained relatively constant across the two studies, presumably because it was most often misidentified as the alphabetic symbol E and its new features did not provide greater differentiation with the E. However, the amount of space between the bottom of the frame and the lower interior line was found to affect tangibility, with a greater number of H/E errors coming at a large font size and a greater number of H/L errors occurring at the smallest font sizes. This suggests that the space should be adjusted according to font size. At large font sizes

there should be less space between the interior line and the lower portion of the frame. Therefore, it is essential that this space be managed through the use of font presentation algorithms.

65. I - Points were added to the frame of the alphabetic symbol I. The most common error in study #2 was when subjects mistakenly identified the alphabetic symbol "I" as the alphabetic symbol "S", or visa versa. This error accounted for 6% of all errors in our second study (see Table 2 (attached to this Declaration)). After redesign, this error was dramatically reduced.

66. J - Points were added to the frame of the alphabetic symbol J. Additionally, the small line inside the frames was shortened. Also, the lines were redesigned so that the side closest to the frame could be more tangible (i.e. its presence would not be blocked by the middle most edge of the interior line). These two changes dramatically reduced the two most common misidentification errors J/I and J/Q from study #2 to study #3.

67. K - Points were added to the frame of the alphabetic symbol K. This, and the improved tangibility of other alphabetic symbols, may have contributed to improved accuracy for the alphabetic symbol K.

68. L - Points were added to the frame of the alphabetic symbol L. The L was rarely misidentified in study # 2. Little about the alphabetic symbol changed and its tangibility was found to be nearly equal in study # 3.

69. M - Points were added to the frame of the alphabetic symbol M. This redesign made little impact on its tangibility, as M was most often confused with another square framed alphabetic symbol.

70. N - Points were added to the frame of the alphabetic symbol N. The new corner points and a redesign of the R resulted in a dramatic improvement in the accuracy rates for the N. The N/R confusion accounted for 3% of all errors. After the redesigns, this confusion was dramatically reduced.

71. O – The alphabetic symbol O remained unchanged.

72. P – The alphabetic symbol P remained largely unchanged after study #2. However, the accuracy rate for the P improved, most likely because the P had been confused with the alphabetic symbols D, E, and R. After the redesign of the frame of the D and E, the R was rarely confused with those alphabetic symbols.

73. Q – The size of the interior line was reduced and the shape of the line was changed (for the reasons described under alphabetic symbol G). This redesign led to a slight decrease in the accuracy.

74. R – The R was changed because it had been most often confused with the alphabetic symbols D and P (due to orientation or because the subject's paper often became askew) and the N, due to a misidentification of the frame.

75. S - The most common error in study #2 was when subjects mistakenly identified the alphabetic symbol "S" as the alphabetic symbol "I", or visa versa. This error accounted for 6% of all errors in our second study (see Table 2 (attached to this Declaration)). After redesign, this error was dramatically reduced.

76. T - Points were added to the frame of the alphabetic symbol T. This improved the tangibility of the T. In study #2, the D/T confusion accounted for 4% of all errors. After the redesign of the alphabetic symbols T and D, the errors rarely occurred.

77. U - Points were added to the frame of the alphabetic symbol U. Additionally, as the Roman Alphabet letter C was found to be very tangible, the alphabetic symbol U may benefit from a break in its frame. It has also been found that the break should be no more than 0.5 cm, as the square alphabetic symbols are more difficult to navigate with large breaks in their frames. These new alphabetic symbols are shown in the patent application.

78. V - Points were added to the frame of the alphabetic symbol V. Additionally, as the Roman Alphabet letter C was found to be very tangible, the alphabetic symbol V may benefit from a break in its frame.

79. W - Points were added to the frame of the alphabetic symbol W. Additionally, as the Roman Alphabet letter C was found to be very tangible, the alphabetic symbol W may benefit from a break in its frame.

80. X - Points were added to the frame of the alphabetic symbol X. Additionally, as the Roman Alphabet letter C was found to be very tangible, the alphabetic symbol X may benefit from a break in its frame.

81. Y - Points were added to the frame of the alphabetic symbol Y. Additionally, as the Roman Alphabet letter C was found to be very tangible, the alphabetic symbol Y may benefit from a break in its frame.

82. Z - Points were added to the frame of the alphabetic symbol Z. Additionally, as the Roman Alphabet letter C was found to be very tangible, the alphabetic symbol Z may benefit from a break in its frame.

83. The most common 10 confusion errors accounted for 34% of all errors (see Table 2). By redesigning these alphabetic symbols, substantial improvements in the utility appear to

have been achieved. The error rates for study #3 (see Table 2, 3 and 8 (attached to this Declaration)) may be indicative of that improvement.

84. *Frame Design*:

85. After study #2, an iterative process of design evaluated several frame configurations to determine what frame shapes were most identifiable (see Table 3 for examples). Those chosen for inclusion in the application were found to be the most tangible. Other shapes evaluated were an ovoid shaped circular frame, a tapered square frame, a square frame with one side missing, and circle and square frames with gaps of varying sizes in their frames. I chose the most tangible of the identified frames. (see Table 1 (attached to this Declaration))

86. *Study #3*:

87. *Overview and Design*:

88. The third study, conducted after the filing of the patent application, gives indication that the redesign had a positive effect on the tangibility of the ELIA® Alphabet. The 60 hours study, which included visually impaired subjects ages 21 to 84, who studied and were tested at font sizes of 0.7 cm, 0.8 cm, 1.1 cm and 1.3 cm, showed that several alphabetic symbols were more tangible. Their test results showed that several confusions present in study #2 were eliminated, by training and/ or by redesign. The elimination of certain frame errors, especially those between the alphabetic symbols A-D and O – S, and the circle / square alphabetic symbols errors, while the errors of less redesigned alphabetic symbol persisted, suggests that the redesign of the frames was effective. The results of study #3 are included only as the most current information available on the tangibility of the ELIA® Alphabet font.

89. While part of the improvement in the accuracy rates between Study #2 and Study#3 may be explained as a function of the study design (training, subject inclusion criteria, or perhaps a change in instruction), the substantial accuracy improvements of those alphabetic symbols whose frame was targeted for redesign due to specific errors, and the absence of those errors in Study #3 results indicates that the redesign was effective. For example, as Table 8 illustrates, the most common frame confusions (I/S, D/T, N/R and E/P) were largely eliminated; meanwhile error rates for other alphabetic symbols where circle / square errors were not a problem in study #2, such as the F, H, and M, remained largely unchanged.

90. *Results / Findings and Broad Changes to Font*:

91. *Element Spacing and Alphabetic Symbol Spacing*:

92. As the information above indicates, the advances in the development of the frame that are delineated in the patent application could not have been derived without the research and iterative design process that the applicant conducted. The same is true for The font described and claimed in the application regarding the combined of the frames and the non constant changes in alphabetic symbol spacing, internal element spacing, multiple colors and line width. These dynamics would not have been obvious without analysis of the research results, which were not public knowledge. For example, the fact that the most common alphabetic symbol confusions could change with font size (e.g. that the misidentifying an F for an L occurred primarily at small font sizes, whereas misidentifying an F for and E was more common at large font sizes) would not have been obvious without the generation and analysis of the research results. The same was true of line width and inter symbol element spacing – the research indicates that these

93. Alphabetic symbol spacing was found to have a significant effect on tangibility. In the Braille group, random symbols widely spaced were identified with greater accuracy than symbols in words. This is despite the benefits of the symbols' context in words. Further testing revealed that with respect to tactile alphabetic symbols, alphabetic symbol spacing should not vary a constant ratio to font size.

94. *Line Width*:

95. Similar findings were identified for line width. It was found that the optimal shape of a tactile line occurs when the printer produces a line that has steep sides and a pointed top surface. If a line is too wide for a printer, then the top side of the line will have a flat construction (because of the way a printer layers raised text). Flat top surfaces are less tangible than pointed top surfaces. Therefore, because tactile printers have limited capacity to produce raised alphabetic symbols, and depending on the printer, at a certain line width the top of a alphabetic symbol must vary according to line width. Otherwise, a wide line will be less tangible. Conversely, if a line is too thin, the maximum raise will not be achieved, due to the production capacity of printers. There may be an optimal line width that must remain constant across font sizes.

96. *Multiple Colors*:

97. It should also be noted that the combination of the frame configurations and the inclusion of multiple colors would also not have been obvious. During the iterative design process the company held multiple focus groups with blind consumers. It was discovered that many of them have enough residual vision that they can leverage their tactile reading with their vision, especially if they are having difficulty identifying a particular alphabetic symbol (they either bring the paper to their eye(s) or lean over so that their head is closer to the page).

Approximately 80% of the legally blind have some useful residual vision but its incorporation into tactile reading would not have been obvious to someone schooled in the cited existing art. Also, most Braille readers were born congenitally blind and do not have residual vision, so research on the use of residual vision by Braille users would not have resulted in this finding. Only through testing non Braille readers who are blind would this have been found. They are usually excluded from tactile reading studies because they are unable to read Braille.

98. I would like to note that Jeffrey described a method of generating and managing fonts that applies to all fonts. However, it would not have been obvious to one who had read the article and of ordinary skill how to apply the art in Jeffrey to Chepaitis '108 and Desrosiers in order to arrive at the inventive font. As described above, application of Jeffrey to the combination of Chepaitis '108 and Desrosiers would have required the generation of extensive research data. Furthermore, while the fonts described in Jeffrey are adjustable, they do not automatically adjust for the configuration needs of a font that is tactile or otherwise intended for the visually impaired. Jeffrey applies to all fonts generated from font generation software.

99. I understand that willful false statements and the like are punishable by fine or imprisonment, or both (under 18 U.S.C. § 1001) and may jeopardize the validity of the application or any patent issuing thereon.

100. All statements made of my own knowledge are true and that all statements made on information and belief are believed to be true.

Date: 2-19-08

Signed: ____________
Andrew Chepaitis

Attachments: Resume of Andrew Chepaitis
A. Chepaitis et al., "Comparison of the ELIA and Braille Tactile Alphabets for Adults Visually Impaired Readers"
Tables 1 - 8

ANDREW J. CHEPAITIS

ELIA Life Technology, Inc. *New York, NY*
President & CEO: *1/98 - Present*

- Executed product development including design and production pricing of initial product
- Raised seed capital financing for company
- Analyzed potential product and services offerings according to return of deployed capital, profit margins, competition, demographics and market research
- Authored comprehensive business plan
- Gathered market research from government, industry, media and consumer groups
- Recruited industry specialists for corporate board and research and development team

Research Support

- Co-Principal Investigator (2000) – Pilot Study for Clinical Research, Research Foundation for the State University of New York ($3,000)
- Co-Principal Investigator (2001 – 2002) – Tactile font evaluation of the Roman Alphabet, ELIA Alphabet and Braille, Funded by the Langeloth Foundation ($119,000)
- Co-Principal Investigator (2004 – 2005) – Comparison of the ELIA and Braille Tactile Alphabets for Adults Visually Impaired Readers. Funded by the Langeloth Foundation ($292,000)
- Principal Investigator (2005 – 2006) – Tactile Font Evaluation Study. Funded by the National Eye Institute NIH SBIR Program ($103,700)

Publications:

Chepaitis, Andrew J., Griffiths, A. Fuzz, Wyatt, Harry, O'Connell, Williams F.. Evaluation of tactile fonts for use by a visually impaired elderly population, *Visual Impairment Research – 2004, Vol. 6 Nos. 2–3,* pp. 111–134

Presentations:

Chepaitis, Andrew, O'Connell, William. Tactile font evaluation of the ELIA Alphabet, American Optometric Association Annual Meeting, Seattle, December, 2000.

Chepaitis, Andrew, O'Connell, William. Tactile font evaluation of the Roman Alphabet, ELIA Alphabet and Braille, American Optometric Association Annual Meeting, Philadelphia, December, 2003.

Chepaitis, Andrew. Tactile Font evaluation of the Roman Alphabet, ELIA Alphabet and Braille – Design Implications for Tactile Fonts, Tactile Research Group Annual Meeting, Orlando, December, 2003.

Chepaitis, Andrew J., Griffiths, A. Fuzz, Wyatt, Harry, O'Connell, Williams F.. A comparative study to test the ability of seniors to learn and read tactile alphabets. Association for Research on Vision and Ophthalmology Annual Meeting, May 4-8, 2003

Chepaitis, Acquilante, Griffiths, Wyatt. Comparison of the ELIA and Braille Tactile Alphabets for Adults Visually Impaired Readers, Association for Research on Vision and Ophthalmology Annual Meeting, April 30 – May 4, 2006

Credit Lyonnais Securities (USA) Inc. *New York, NY*
Equity Research Department:
Junior Analyst - Telecommunications & Cable *1/95 - 12/97*

- Built & maintained financial models
- Performed financial reseach analysis of companies under coverage
- Compiled telecommunications industry & technology data for cable industry reports

Assistant Analyst - Latin American and European Research *3/94 - 6/95*

- Produced monthly research publications for investment banking, sales and trading
- Managed 46,000 cell database

EDUCATION

Lehigh University, *Bethlehem, PA - BA International Business* *1990*

University of New Haven, *West Haven, CT - MBA Finance / Industrial Psychology* *1992*

ADDITIONAL INFORMATION

Association for Research on Vision and Ophthalmology (Member 2001 – 2008), Tactile Research Group (2001 – 2008), Regional Vice President of the Lehigh Alumni Association (2002 – 2006); President of the Lehigh Alumni Association of New York City (1997 – 2002); Hopkins School Alumni Association Board Member (2000 – 2008);

TABLE 1: ELIA® 1st Tested Font vs. ELIA® 2nd Tested font

1	2	3	4	5	6	7	8	9	10	11
Letter	Rate of use	Letter Rank	Original Font	Error Rating	Font #1	Error %	Font #2	Error %	Utility Rating 1st Font	Utility Rating 2nd Font
A	8.50%	2		B		9%		2%	8.1	1.5
B	2.07%	17		B		15%		3%	3.1	0.6
C	4.54%	10		B		18%		2%	8.0	0.9
D	3.38%	12		T		8%		2%	2.9	0.7
E	11.16%	1		T		9%		4%	10.0	3.9
F	1.81%	18		B		15%		13%	2.7	2.4
G	2.47%	16		T		14%		3%	3.3	0.8
H	3.00%	15		B		7%		8%	2.0	2.4
I	7.54%	4		T		10%		5%	7.3	3.5
J	0.20%	25		B		18%		11%	0.3	0.2
K	1.10%	21		B		29%		17%	3.2	1.8
L	5.49%	9		T		2%		1%	1.3	0.3
M	3.01%	14		B		13%		12%	4.0	3.6
N	6.65%	7		T		12%		3%	8.1	1.9
O	7.16%	5		T		0%		2%	-	1.1
P	3.17%	13		T		20%		12%	6.3	3.7
Q	0.20%	26		T		11%		16%	0.2	0.3
R	7.58%	3		T		14%		7%	10.6	5.3
S	5.74%	8		B		6%		5%	3.6	3.1
T	6.95%	6		T		5%		3%	3.6	2.2
U	3.63%	11		B		15%		10%	5.6	3.5
V	1.01%	22		T		18%		16%	1.8	1.6
W	1.29%	20		B		18%		14%	2.4	1.8
X	0.29%	23		B		23%		12%	0.7	0.4
Y	1.78%	19		B		17%		15%	3.1	2.7
Z	0.27%	24		T		19%		15%	0.5	0.4
Total						11%		8%	102.4	50.6

T = Top 50% of the alphabet, B= Bottom 50% of the alphabet. The Utility Rating qualifies the utility of the alphabet as it is read in the English language. It is derived by multiplying the Rate of Use (column 1) by the Error % (column 5 or column 7). The maximum Utility Rating would be 1,000, which would mean that all letters were incorrectly identified 100% of the time.

Table 2

Rank	Study #2 on Font #1	% of Total Errors	Frequency of Use	Rank	Study #3 on Font #2	% of Total Errors	Frequency of Use
1	I/S	6%	13%	1	U/V	5%	5%
2	E/H	5%	14%	2	Q/O	4%	7%
3	N/R	4%	14%	3	F/Y	4%	4%
4	D/T	4%	10%	4	M/Y	3%	5%
5	A/O	3%	16%	5	K/J	3%	1%
6	A/C	3%	13%	6	L/F	3%	7%
7	U/L	2%	9%	7	X/Z	3%	1%
8	E/P	2%	14%	8	S/R	3%	13%
9	H/F	2%	5%	9	V/K	2%	2%
10	I/W	2%	9%	10	R/P	2%	11%
Total		34%		Total		34%	

The percentage of total errors in final testing is shown, as is the frequency with which these alphabetic symbols are used in the English language. For example, I is 7.5% of all alphabetic symbols used, and the alphabetic symbol S is used 5.7% of the time. The frequency with which a reader finds one of them in the English language is therefore 13.2% of all alphabetic symbols read.

TABLE 3 - Alternative Configurations Evaluated

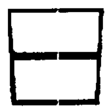
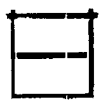
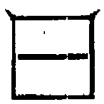
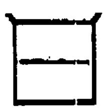
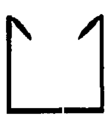
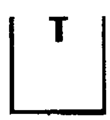
Ovoid Circular Frame				
Ovoid Circular Open Frame				
Tapered Square Frame				
Crossed Corners				
Pointed Corners				
Line Point Corners				
Line Point Corners Open Frame				
Broken Square Frame				
Filled Area Frame				

Table 4

	Finding	Alphabetic symbols Affected and redesigned
1	Close parallel and nearly parallel tactile lines are difficult to feel. Later, we would identify the fact that parallel lines should not be closer that XX mm together.	All Capital Alphabetic symbols C, F, H, M, S, U, W
2	Where interior lines and exterior frame meet, readers have difficulty identifying the characteristics, features and configurations of the lines. For example, elements that were located in corners of a square frame were identified as difficult to feel.	A, J, K, M, U, V, W, Y and X
3	Alphabetic symbols with elements in similar internal configurations, were often incorrectly identified by readers as another specific alphabetic symbol.	F / M / U were commonly confused. H / W were paired confusions. S / R were paired confusions
4	Alphabetic symbols with elements in similar internal configurations, were asymmetrically misidentified by readers as a alphabetic symbol that was highly tangible.	C was misidentified as the alphabetic symbol O F and H were misidentified as an E G was misidentified as the alphabetic symbol I K was misidentified as the alphabetic symbol T
5	The more internal lines a alphabetic symbol has, the less tangible it is.	A, K, V and X
6	The more open space inside the alphabetic symbol, the more tangible it is. Also the shape of the open space is an important cue for readers of a framed tactile alphabet	A, F, H, J, K, M, S, U, V, W, Y

Table 5

	Finding	Alphabetic symbols affected and redesigned
1	Of all errors, XX% occurred when a circular framed alphabetic symbol was misidentified as a square framed alphabetic symbol, or visa versa.	A – N, T – Z (affected and redesigned)
	Errors where the subject correctly identified the interior element and misidentified the circular or square frames were common, accounting for 17% of errors.	D / T, E / P, I / S, N / R, Q / W (affected) D, T, E, I, N, R, Q, W (redesigned)
2	In the Roman alphabet group, the letter C was identified with high accuracy rates (97%). This was higher than all the alphabetic symbols A-D in the ELIA® Alphabet (though the ELIA® Alphabet alphabetic symbols A, B and D were more tangible than their Roman counterparts). See table 6 for mean error rate comparisons between the alphabets.	A, B, C and D (affected and redesigned)
3	In the ELIA® Alphabet group 9% of all errors were a misidentification of a circular alphabetic symbol in the first group for a circular alphabetic symbol in the second group, or visa versa. Another 3% of all errors were between the alphabetic symbols A and C.	A – D, O – S (affected) A – D (redesigned)
4	In the Roman alphabet group, the letter D was misidentified 20% of the time. This was a critical finding with regards to how square and circular frames are identified. The most common error was a misidentification of the D as an O (suggesting that the corners were difficult to identify). In the ELIA® Alphabet, this was not a common error, and the D was identified correctly 92% of the time.	E – N, T – Z (affected and redesigned with pointed corners)
5	Intra symbol spacing - The spacing of interior elements affected performance. For example, G, J, M, W, Q were most commonly misidentified as I or S. Reducing the size of these alphabetic symbols' lines improves performance at some sizes, but reduces performance at other sizes.	B, F, G, H, J, K, M, Q, R, U, V, W, Y (affected)
6	Inter symbol spacing – It was found that tactile alphabetic symbols were more difficult to feel with reduced inter symbol spacing. However, the marginal utility of additional space at larger font sizes, if the font were scaled proportionally, declines, wasting space and reducing tangibility at some point.	All alphabetic symbols (affected)
7	Frame gap size – the size of any gap in the frame must be carefully managed, because if it is too big, readers will lose there finger positioning and thereby their reading ability.	A, B, C, D, U, V, W, X, Y, Z (affected and redesigned)
8	Location on a page – efficient readers use different fingers to read in different portions of the page. For example, readers use their index fingers to read most alphabetic symbols, however, at the end of a line of text, they may use their middle fingers to save hand movement time. These fingers usually have less tactile acuity and therefore the alphabetic symbols have to be slightly larger than the alphabetic symbols found in the middle of the page.	All alphabetic symbols (affected and redesigned)

Table 6

Total Roman Actual	Error %
A	23.3%
B	27.4%
C	3.1%
D	20.0%
E	17.5%
F	29.3%
G	17.0%
H	28.4%
I	24.7%
J	13.0%
K	39.7%
L	17.4%
M	50.0%
N	22.6%
O	0.8%
P	12.0%
Q	18.9%
R	25.6%
S	22.3%
T	14.4%
U	6.6%
V	12.2%
W	20.0%
X	46.1%
Y	27.3%
Z	49.6%
Average	21.7%

Total ELIA® Actual	Error %
A	9%
B	15%
C	18%
D	8%
E	9%
F	15%
G	14%
H	7%
I	10%
J	18%
K	29%
L	2%
M	13%
N	12%
O	0%
P	20%
Q	11%
R	14%
S	6%
T	5%
U	15%
V	18%
W	18%
X	23%
Y	17%
Z	19%
Average	10.8%

Total Braille	Error %
A	6.3%
B	21.9%
C	25.2%
D	51.0%
E	34.7%
F	50.0%
G	38.9%
H	43.6%
I	44.4%
J	53.8%
K	33.0%
L	25.5%
M	50.8%
N	26.3%
O	60.0%
P	59.5%
Q	55.8%
R	63.3%
S	66.2%
T	66.7%
U	55.6%
Average	43.4%

Table 7 – Study #2 Confusion Matrix

Total	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	NA	Errors	Total	Error %
A	X	1	6	2		1	1						1		15			1						1			4	33	348	9%
B	2	X			1	1		1								4					1			1				11	74	15%
C	7		X	1		1	6								2		1		4		2							24	137	18%
D	1			X												1		2		5			1					10	118	8%
E		2			X	1		15					1	2		4		2		2							2	31	347	9%
F					1	X		9			1	3								4							2	20	136	15%
G			1				X	1	2								2				2							8	59	14%
H		1			7	3		X				2			1					1		1					1	17	256	7%
I					1		1		X	3								2	20	1			5					33	340	10%
J									6	X	4					1	5					2		2				20	114	18%
K	1			2			1	2		2	X	2			2					1	1	5		1			4	24	83	29%
L												X			1					1				1				3	125	2%
M	1								1	1		1	X						1	2			4		2		1	14	105	13%
N				1					1		5			X		1		9		2				1			2	22	180	12%
O															X													-	282	0%
P	1	3		1	8						1				1	X		4	1									20	101	20%
Q										3	1						X		1									5	47	11%
R				5										9		5		X		4				1			4	28	201	14%
S	2	1		1					8					1	1		1	3	X			1					2	21	338	6%
T	1			13	1						1		3	3						X	2					1		25	489	5%
U			1							1		12			2						X							16	104	15%
V	1										4			1							2	X		2				10	57	18%
W				1				1	6	4			1	1			2		3	3	2		X	1			1	26	141	18%
X	2	1			3		1	3		1	8			2				2		1	1	2		X		1	4	32	138	23%
Y	2		2	1		2			1				2												X		1	11	63	17%
Z	1			1	1						5			8		2				3				1		X	2	24	128	19%
	22	9	10	29	23	9	10	32	25	15	30	20	8	27	25	18	11	25	30	30	13	11	10	12	2	2	30	488	4,511	11%

Table 8 – Study #3 Confusion Matrix

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	NA	Errors	Attempts	Error %
A				2	1																							3	174	2%
B	1		2		2			1								1												7	240	3%
C	1	1																									1	3	152	2%
D	2																		1								1	4	182	2%
E		1		1		1						1		2						1	1					1		9	257	4%
F			2	1	2							14	5		2	1									4		1	32	245	13%
G									1	1	1	2	1													1		7	225	3%
H		3			4	1					3	2										3					1	17	211	8%
I							1						1					1	4				2	1	1			11	235	5%
J						1		1			4	3			3							5	2				1	20	174	11%
K				1		1	1	1		11		6	2		5			1		1	1	5					2	38	228	17%
L															1													1	182	1%
M						2	1					7			1					3				2	8		1	25	208	12%
N				1																1	1			1			1	5	172	3%
O			1														1										1	3	191	2%
P		2			1										1		2	8	5								2	21	181	12%
Q			6			1	2					1			16				3		2					1		32	205	16%
R	1														1	1			6									9	129	7%
S													1		1		1	7		1							1	12	219	5%
T									1					3													1	5	158	3%
U							2			1												5	1			3	1	13	135	10%
V				1	1					1	4	1			1						18			1			1	29	180	16%
W		1				1		2	7	2		2								1	2	2					4	24	174	14%
X					1			1	2		3	1		7				2		3		1			2	6	1	30	247	12%
Y		2			1	13	3	1				1	7	1									2	1			1	33	219	15%
Z				4	1	1			2			1	1	7	4	1				2	3	2		8			5	42	288	15%
Sum	5	10	11	11	14	22	10	7	13	16	15	42	18	20	36	4	4	19	19	13	28	23	7	14	15	12	27	435	5,211	8.35%

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Evaluation of tactile fonts for use by a visually impaired elderly population

Andrew Chepaitis [a]; Fuzz Griffiths [a]; Harry Wyatt [a]; William O'Connell [a]
[a] SUNY College of Optometry New York, NY USA.

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Evaluation of tactile fonts for use by a visually impaired elderly population

Andrew J. Chepaitis
A. Fuzz Griffiths
Harry J. Wyatt
William F. O'Connell

SUNY College of Optometry, New York, NY, USA

Abstract *Purpose:* To study the learning and reading of tactile fonts by seniors. *Design:* One hundred blindfolded subjects age 65 years and older were taught and studied one of three tactile fonts: a new font named ELIA, the standard Braille font, or a raised Roman font. *Methods:* ELIA and Roman texts were presented at letter heights of 1.0 cm, 1.1 cm, 1.2 cm, and 1.3 cm, while Braille texts were presented at the standard size (0.7 cm). Training lasted for 30 hours. Test stimuli were presented as single letters in random order or as words in sentences. *Results:* It was found that ELIA was read with greater speed and letter recognition accuracy than the Roman font and that both the ELIA and Roman fonts were read with greater speed and accuracy than the Braille font. *Implications:* Most seniors are capable of reading tactile fonts, which can be utilized to achieve greater independence.

Key words Seniors; reading; tactile font; Braille; ELIA

Introduction The purpose of this work was to determine whether subjects 65 years of age and older can learn and read tactile fonts. In the past, research has been conducted on tactile perception in this population,[1–6] but, to the best of the authors' knowledge, in-depth research has not been conducted on tactile learning and reading by seniors.

The growth of the elderly population and the high rates of visual impairment among the elderly are resulting in substantial increases in the societal cost of visual impairment. A major factor behind these costs is the reduced ability of visually impaired persons to care for themselves and remain in contact with their living environment and support community. Eighty-eight percent of severely visually impaired persons age 65 and older have difficulty completing daily living activities that are essential for independent living, such as preparing a meal, taking medication, or dressing oneself.[7] New approaches to these

Correspondence and reprint requests to:
Andrew J. Chepaitis
SUNY College of Optometry
33 W. 42nd St.
New York, NY 10036
USA
E-mail: ajchep@earthlink.net

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	Number of subjects per group		Sex of subjects		Mean age
	Initial	Final	Male	Female	
ELIA	35	29	8	21	71.9
Roman	46	38	15	23	71.7
Braille	35	33	9	24	71.7
Total	116	100	32	68	71.7

TABLE 1. Subject group sizes and demographics. The sex and age of all subjects who completed the final session. 'Initial' means the number of subjects admitted to each group of the study and 'final' the number that completed the study.

to the groups, 100 completed the study. There were a number of reasons that subjects did not complete the study. The two most frequently given reasons were health problems and changes in summer vacation plans.

Informed written consent was obtained from all subjects, as per the regulations of the Institutional Review Board at the host institution, and all experiments were conducted in accordance with the guidelines of the 'Declaration of Helsinki'.

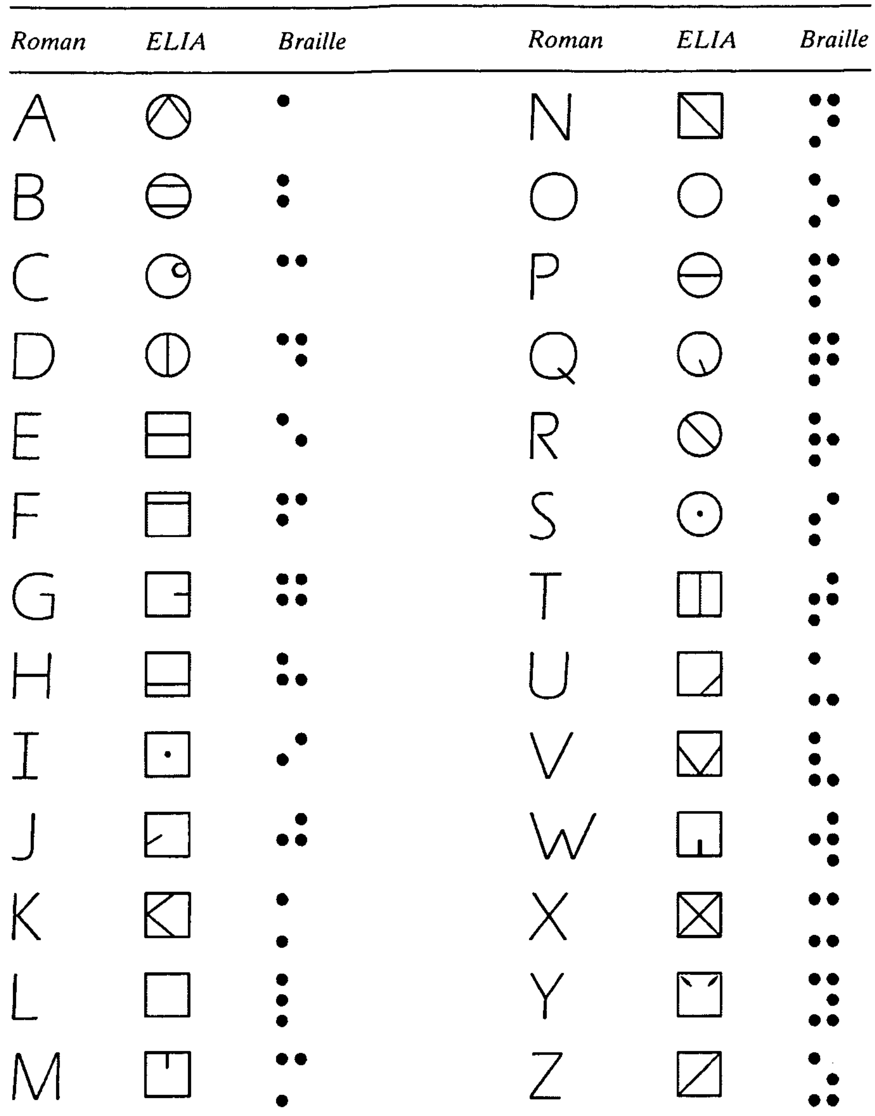
STIMULI

ELIA font The ELIA font[11] (Table 2) was designed for persons who were not learning Braille and who were adventitiously blinded after having read print for most of their lives, especially seniors. Principles from human factors engineering were applied to the design of the font. Specifically, the letters feature major characteristics of corresponding Roman alphabet letters so that people learning ELIA can build on their existing knowledge of the Roman alphabet, and the letters utilize a frame that aids readers in differentiating between symbols.

ELIA's design includes both an outside frame and an inside element that were hypothesized to offer advantages over Roman alphabet fonts. The frame is a unique feature of this tactile alphabet and was expected to serve five purposes: (1) it would help readers discriminate where one letter ended and another one began; (2) readers could explore each letter in a systematic manner, aiding in accuracy and speed of recognition; (3) the shape of the frame itself provides an additional cue to recognition by narrowing down the set of possible responses; (4) the frame provides frame-of-reference assistance when letters were presented at different font sizes; and (5) the frame was expected to be integrated with the interior elements to provide a symbol that was similar to the Roman letter counterparts. For example, the Roman letters C, D, E, F, G, H, J, K, L, M, N, O, T, U, V, W, X, and Z can be traced in the corresponding ELIA letters.

A number of different font sizes were used in this study. Font size was defined as the maximum height (in centimeters) of the individual characters. For the ELIA font, this is the same as the character width, since the frames are all either square or circular.

TABLE 2. Representations of the three fonts used during the study.



Modified eras light roman font Eras Light ITC (© International Typeface Corporation) was chosen because the letters had aspect (height/width) ratios and letter line widths that were most similar to those of ELIA. Based on preliminary testing, these line widths appeared to be optimal for tactile recognition of text from the computer printers available for use in the study. The font's I, Q, and W were modified to produce a font that had more standardized features than the original (Table 3).

Braille font Braille (see Table 2) was included so that comparisons between the present standard and possible alternative fonts for the elderly could be studied. Because Braille is not presently used as a scalable font, it was presented in standard size, which has a height of 0.7 cm. Other reasons for limiting Braille to standard size were: (1) the space between Braille dots holds meaning and presenting more than one size may have required significant re-learning;[3] (2) there are no

technical support. This research was supported by a grant from the Langeloth Foundation.
Portions of this work were presented at the 2001 American Optometry Association convention[25] and the 2003 Spring Meeting of the Association for Research in Vision and Ophthalmology.[26]
Andrew Chepaitis owns shares of ELIA Life Technology, which holds patents relating to the ELIA Alphabet.

limitations, such as the use of tactile fonts, could enable seniors to achieve an improved quality of life and greater independence while yielding substantial health-care cost savings and higher employment rates.

Among the 1.1 million severely visually impaired individuals ages 65 and older in the U.S., the majority was previously sighted and formerly read print.[7] While Braille is an outstanding independence tool for those who are able to use it, only 8000 seniors read Braille[8] and many of them learned Braille as children. There are a number of possible reasons for Braille's lack of widespread adoption, especially among the former print readers and those over 65. Some reasons that have been cited are that Braille patterns do not have outline shapes that help former readers to identify letters,[3] that above-average intelligence may be required to learn Braille letters,[2] that tactile acuity declines with age to a point where the breakdown in spatial resolution may hamper tactile reading of Braille, especially among the elderly,[5] and that former print readers' use of haptics is influenced by early visual experience, i.e. their visual knowledge of shapes influences their ability to discern and identify tactile shapes.[9]

The plan for the present study was to teach and assess, over time, tactile recognition of a raised traditional Roman font, standard Braille, and a new font named ELIA. The Roman and ELIA fonts were tested at varying font sizes and their results were compared to each other and to standard-size Braille results. Letter recognition speed and accuracy were measured in tasks that varied letter size, context, and spacing.

Materials and methods

SUBJECT RECRUITMENT, SCREENING, AND ASSIGNMENT Participants for the subject groups were recruited from the optometric center's patient database and from local senior centers. Potential subjects were screened for (English) literacy, tactile acuity, and age. A Gray Oral Reading Test[10] was administered to determine literacy. A tactile acuity test consisting of tactile circles and squares of varying heights was also administered. Potential subjects who could not distinguish eight out of ten raised circles and squares of 1.4 cm in height and width and 0.12 mm in raise off the page were excluded from the study. Only subjects 65 years of age and older who passed the reading and tactile acuity tests were enrolled and subsequently randomly assigned to one of three groups. Of the 132 subjects screened, 116 were admitted to the study (Table 1). Of those excluded from the study, two were excluded because of literacy concerns, 10 for lack of sufficient tactile acuity, and four for both literacy concerns and lack of sufficient tactile acuity.

The subject groups were divided according to the anticipated attrition rates. Thirty-five subjects were placed in both the ELIA and Braille groups and 46 were placed in the Roman group, as the researchers anticipated that the Roman group might find their task more monotonous than the other two groups. Of the 116 subjects initially assigned

TABLE 3. Modifications to the Roman alphabet font.

Original Eras Light Letters	I	Q	W
Modified Eras Light Letters	I	Q	W

established methods for switching students between Braille font sizes; (3) Pester and colleagues[12] found that while extra spacing is helpful for beginning learners, the size of Braille characters made no difference in the performance of learners and that standard Braille was more rapidly discriminated; (4) the aim of this research was to compare commercially available tactile fonts; (5) standard Braille is widely available and used by nearly all Braille readers; and (6) the commercially produced manuals and training materials were available in standard-size Braille. This is not to say that alternative Braille font sizes could not be used with the subject population, only that they could not be used in this study.

Nearly all of the instructional materials for the Braille group were purchased from the American Printing House for the Blind (APH). In order to provide consistent-quality Braille text that was age-targeted, subjects were primarily taught Braille using *The Braille Connection*,[13] which was developed for adventitiously blinded adults and published by the APH. *The Braille Connection* is the APH's updated version of the *Read Again* textbook,[14] which Holbrook and Koenig[15] recommend over other textbooks and which was one of the two most widely used textbooks for teaching adventitiously blinded adults.[16] Through the American Foundation for the Blind, a Braille production specialist was contracted to produce the study's additional materials, specifically the testing materials and MNRead sentences.[17] The raise quality of the materials produced by our specialist was comparable to or better than those of the APH instructional texts. All testing materials and any additional instructional material had double-standard Braille line spacing between lines of letters, as recommended by Pester et al.[12]

TEXT PRODUCTION The ELIA and Roman font practice and testing materials were produced with a Tektronix Phaser 600 wax jet printer configured through software to overprint images four times. The raise of the letters was measured using a slitlamp with a reticle in the eyepiece. Data were obtained from 10 measurements per font. ELIA print was found to have a mean uniform raise of 0.12 mm with a standard deviation of 0.02 mm, while Roman print had a mean raise of 0.13 mm with a standard deviation of 0.01 mm.

TRAINING PROCEDURES The study materials for the ELIA and Roman groups consisted of an instruction book modeled after the APH's *The Braille Connection*.[13] For each of the three groups, instruction consisted of 1½-hour study sessions, which met four times per week over five weeks, for a total of 30 hours of training. Subjects were not allowed visual access to the tactile fonts or texts at any time during the

30 hours of study or outside of the classroom, and they were blindfolded while texts were presented to them. Five-to-ten minute breaks were given to the subjects twice per session, during which study materials were either removed from the subjects' desks or covered. The study period duration (75 min of instruction time per session) is consistent with previously reported instruction times, and the frequency and duration of study periods (daily for 5 weeks) was at the high end of the range of recommended instructional intensity.[18]

There were four instructors for the ELIA group, five for the Roman group, and five for the Braille group. One Braille teacher took part in each study session, and led all of the Braille and Roman instruction. One of the authors (AJC) led the ELIA subject group through instruction, but was not present during instruction and testing of the Braille and Roman groups. The other instructors were graduate students under the supervision of the head instructors. For the ELIA and Braille groups, all instructors were required to learn the respective fonts. The additional instructors were employed for testing sessions so that all subjects could be tested during the same session. An additional instructor was included for the Roman group as it was larger than the ELIA group and the additional instructor held relatively constant the ratio of subjects to instructors. The additional instructor was included for the Braille group because the subjects learning Braille were expected to require more assistance, given the reported difficulty that former print readers have learning Braille.[3]

All subjects had access to a guide sheet with their group's respective font on it. The font was printed in order in two columns side-by-side, letters A through M in the left-hand column and N through Z in the right-hand column. The sheet was enclosed in a small folder taped to the subjects' desks. The folder was open as a tactile reference tool during supervised training, but was kept closed at all other times. These guide sheets enabled the subjects to study with a greater level of independence from the instructors than would have otherwise been possible.

Table 4 shows the sequence of training and testing. In the first week of instruction, the ELIA and Roman groups were taught roughly half of the alphabet (A–E, I, L, O–S for ELIA and A–M for Roman). The rest of the alphabet was taught during the second week of classes. For the remaining 18 hours, ELIA and Roman subjects were given supervised practice exercises using a set of 180 MNRead sentences.[17] This practice involved the subject reading independently and raising a hand when finished with the available text, at which point an instructor would bring them new text and the subject would either read back the text to the instructor and receive a new sheet, or, if comfortable that they had mastered the materials, just receive a new sheet of text and continue reading. In all three groups, subjects would occasionally ask instructors for assistance with reading the letters or words in the practice exercises if he/she was not able to distinguish the letters using his/her individual guide sheet.

The Braille group was taught the letters A–E in week one, A–J in week two, A–M in week three, A–P in week four, and A–U in week five. This group needed considerably more ongoing assistance than the

TABLE 4. Summary of the training and testing schedule.

Study hours	*Study group practice content*		
	ELIA	*Roman*	*Braille*
Week 1 / Hours 0–6	A–E, I, L, O–S	A–M	Letters A–E
Week 2 / Hours 7–12	A–Z	A–Z	Letters A–J
Week 3 / Hours 13–18	MNRead sentences	MNRead sentences	Letters A–M
Week 4 / Hours 19–24	MNRead sentences	MNRead sentences	Letters A–P
Week 5 / Hours 25–30	MNRead sentences	MNRead sentences	Letters A–U

Test	*Test type*	*Test content & font sizes tested*		
		ELIA	*Roman*	*Braille*
	Random-letter testing			
RL 1	Study prior to RL1 / BRL 1	12 hours	12 hours	15 hours
	Test content and font sizes	A–Z at 1.1–1.3 cm	A–Z at 1.1–1.3 cm	A–J at 0.7 cm
RL 2	Study prior to RL2 / BRL 2	18 hours	18 hours	24 hours
	Test content and font sizes	A–Z at 1.0–1.3 cm	A–Z at 1.0–1.3 cm	A–P at 0.7 cm
RL3	Study prior to RL3 / BRL 3	25 hours	25 hours	29 hours
	Test content and font sizes	A–Z at 1.0–1.3 cm	A–Z at 1.0–1.3 cm	A–U at 0.7 cm
RL4	Study prior to RL4	29 hours	29 hours	NA
	Test content and font sizes	A–Z at 1.0–1.3 cm	A–Z at 1.0–1.3 cm	NA
	Letter-in-word testing			
LIW 1	Study prior to LIW1 / BLIW	24 hours	24 hours	29 hours
	Test content and font sizes	A–Z at 1.0–1.3 cm	A–Z at 1.0–1.3 cm	A–U at 0.7 cm
LIW 2	Study prior to LIW2	29 hours	29 hours	NA
	Test content and font sizes	A–Z at 1.0–1.3 cm	A–Z at 1.0–1.3 cm	NA

Roman and ELIA Groups, as they progressed slowly through learning the alphabet and were not able to complete learning the entire alphabet over the course of the study.

Letters in the Roman font were uppercase and letters in the ELIA font and Braille were lowercase. Uppercase ELIA symbols and uppercase Braille symbols are identical to their respective lowercase letters except for the addition of a dot above (for ELIA) or before (for Braille) the lowercase symbols. ELIA and Roman texts were presented at font sizes of 1.0, 1.1, 1.2, and 1.3 cm. All ELIA and Roman instructional materials were presented at font size 1.2 cm until session 8. In session 8, subjects studied for ½ hour before they were tested on random-letter recognition for all 26 ELIA or Roman letter shapes. Subjects were tested at font sizes of 1.3 cm, 1.2 cm, and 1.1 cm. After the session 8 testing, subjects read MNRead sentences as practice exercises. Tactile texts were available with 1.3-cm, 1.2-cm, 1.1-cm, and 1.0-cm letter heights (1.0 cm was available after hour 15). Subjects read texts in the smallest font with which, in testing, they had read at least seven characters correctly during a two-minute test with an accuracy rate of at least 70%. If a subject did not achieve this score on any font size, he/she continued reading with 1.2-cm texts. There were 90 pages of text

available to read in each font size, and each page contained two MNRead sentences.

TESTING PROCEDURES Two types of tests were administered to the groups – random-letter (RL) tests and letters-in-words (LIW) tests. Each test session consisted of three or four tests, each at a single font size. Each RL test was two minutes in length and tested subjects on their ability to identify random letters at a given font size. Letters were widely spaced and without context. Random letters were presented with space between them to ascertain whether the subjects could identify individual characters while minimizing the potential for lateral masking interference from adjacent letters. There were nine to eleven letters per line, depending on font size. For the ELIA and Roman groups, subjects were tested on font sizes ranging from 1.0 to 1.3 cm in height, which were presented with 1.1–1.4 cm of space between the outer edges of the random letters. For the Braille group, subjects were given RL tests with letters at the standard height (0.7 cm) and with standard interword spacing (0.6 cm). Braille results from identical size tests were averaged together.

LIW tests were MNRead sentences,[17] which are composed of 51 characters using words with high frequency, equivalent to a third-grade reading level. LIW tests were administered to ascertain if subjects could successfully read tactile text and if so, at what speed and accuracy. Each testing session consisted of three to four tests that were each two minutes in length. Each test presented text at one font size, either 0.7, 1.0, 1.1, 1.2, or 1.3 cm. In LIW tests for the ELIA and Roman groups, the letters were 1.0–1.3 cm in height and spaced 0.4–0.5 cm apart within words and 1.1–1.4 cm between words, depending on the font size. In LIW testing, Braille letters were spaced according to present Library of Congress standards, 0.25 cm apart within words and 0.9 cm apart between words.

The Roman and ELIA groups were tested with RL tests of the full alphabet in sessions 8 (Test 'RL1'), 12 (Test 'RL2'), 17 (Test 'RL3'), and 20 (Test 'RL4') and with LIW tests in session 16 (Test 'LIW1') and session 20 (Test 'LIW2'), which were one week apart. The Braille group was tested with subsets of the full alphabet in sessions 10 (letters a–j, Test 'BRL1'), 16 (letters a–p, Test 'BRL2'), and 20 (letters a–u, Tests 'BRL3' and 'BLIW'). Roman and ELIA groups were tested using font sizes 1.1, 1.2, and 1.3 cm in Test RL1 and font sizes 1.0, 1.1, 1.2, and 1.3 in tests RL2, RL3, RL4, LIW1, and LIW2.

Testing measurements were as follows. Speed was measured as the number of letters attempted in two minutes (laptm). Score was the number of correct letters identified in two minutes (clptm). Accuracy was calculated as the number of letters correctly identified in two minutes divided by the number of letters attempted in two minutes, i.e. the score over the speed. Words per two minutes (wptm) was measured in LIW tests as the number of words that were correctly identified in two minutes. Speed was included because the rate at which subjects attempted to read is an important indicator of their ability to navigate each alphabet's characters.

Instructions to the subjects before the tests were to 'Please read the letters as quickly and accurately as you comfortably can'. Scoring was explained to the subjects before each set of tests. It was also explained that the only feedback they would receive during the test was a verbal 'OK' that would let them know that the instructor had registered their answer. The ELIA and Roman tests were given in order of descending size, with the largest font size presented first. The Braille group was given an equivalent number of tests at the standard size.

Results were recorded as follows. As the subjects read their tactile copy of each test, instructors marked a (visual) print copy of the test, recording correct and incorrect answers on the print copy. Words verbally identified were also registered. If a subject identified all the letters of a word correctly and stated the word, the letters and word were marked as identified. If the subject identified all the letters in a word but did not say the word, the letters of the word were marked as correctly identified and the word was marked as not identified. In terms of letters identified, if a subject touched a letter but gave no answer, the letter was marked as 'attempted/incorrect' in the results of the subject. If the subject did not touch the symbol, for example if the subject skipped an entire line of symbols due to a tracking error, the missed letters were not counted in the results of the subject.

Results The mean score, speed, and accuracy were calculated for each of the RL and LIW tests. From the final test data, the effects of alphabet type, font size, and test type (RL vs. LIW) were evaluated, and results from the first test and the last test (for the ELIA and Roman groups) were compared to determine the effects of training.

ROMAN GROUP

Random-letter tests In the Roman group, the average score increased by 54% from Test RL1 to Test RL4 (Figure 1, Table 5). However, improvement and final performance varied greatly within the subject group, with score improvement (the difference between the results of the first and last tests) ranging from 0 to 15 clptm and final scores ranging from 0 to 35 clptm. The scores ranged from 0 to 34 (speed range: 3–35; accuracy range: 0–100%) for the largest font size (1.3 cm) and from 1 to 32 (speed range: 5–34; accuracy range: 9–100%) for the smallest font (1.0 cm). As shown in Table 5, the Roman group subjects enjoyed the greatest accuracy with the largest letters (1.3 cm in height), while lower performance was evident with the smallest font size (1.0 cm).

Letters-in-words tests Tests LIW1 and LIW2 were administered one week apart, during sessions 16 and 20 of the study. As with the RL tests, the final LIW test scores of the Roman group also varied widely with ranges for score, speed, and accuracy of 0–42, 3–43, and 0–100%, respectively, for 1.3-cm letters and 0–41, 3–41, and 0–100%, respectively, for 1.0-cm letters (Figure 2, Table 6). The scores of the Roman

TABLE 5. Summary of the random-letter (RL) test results from the Roman and ELIA groups. Three measures of performance were computed: the number of letters correctly identified per two minute test (score), the number of letters attempted per two minute test (speed), and the percentage accuracy at which letters were identified. Mean (Average) and standard deviation (SD) were computed across all font sizes for each test session.

	Random-letter tests: Roman group				*Random-letter tests: ELIA group*			
	Test RL 1	*Test RL 2*	*Test RL 3*	*Test RL 4*	*Test RL 1*	*Test RL 2*	*Test RL 3*	*Test RL 4*
Score								
1.0 cm	NA	8.82	8.53	8.95	NA	10.00	11.03	14.00
1.1 cm	6.89	8.18	8.45	10.32	6.55	9.17	10.93	14.72
1.2 cm	6.24	7.84	7.34	9.84	6.72	11.10	11.41	14.52
1.3 cm	7.03	9.05	9.16	12.39	7.00	11.52	12.52	16.86
Average	6.72	8.47	8.37	10.38	6.76	10.45	11.47	15.03
SD	5.03	6.38	6.58	7.79	4.97	9.34	7.58	11.38
Accuracy								
1.0 cm	NA	64%	58%	61%	NA	63%	68%	75%
1.1 cm	58%	64%	59%	65%	57%	60%	70%	73%
1.2 cm	52%	64%	58%	66%	61%	77%	73%	76%
1.3 cm	62%	65%	63%	76%	62%	76%	80%	85%
Average	57%	64%	59%	67%	60%	69%	73%	77%
SD	29%	29%	28%	26%	27%	26%	23%	21%
Speed								
1.0 cm	NA	12.13	13.03	13.24	NA	14.82	15.07	17.38
1.1 cm	10.74	11.54	12.34	13.66	10.18	13.25	14.64	17.97
1.2 cm	10.13	10.84	11.45	13.58	10.21	13.57	14.79	17.34
1.3 cm	9.63	11.47	12.53	14.95	10.75	14.00	14.66	19.21
Average	10.17	11.50	12.34	13.86	10.38	13.91	14.79	17.97
SD	5.25	5.92	6.24	6.87	4.48	8.50	6.76	10.88

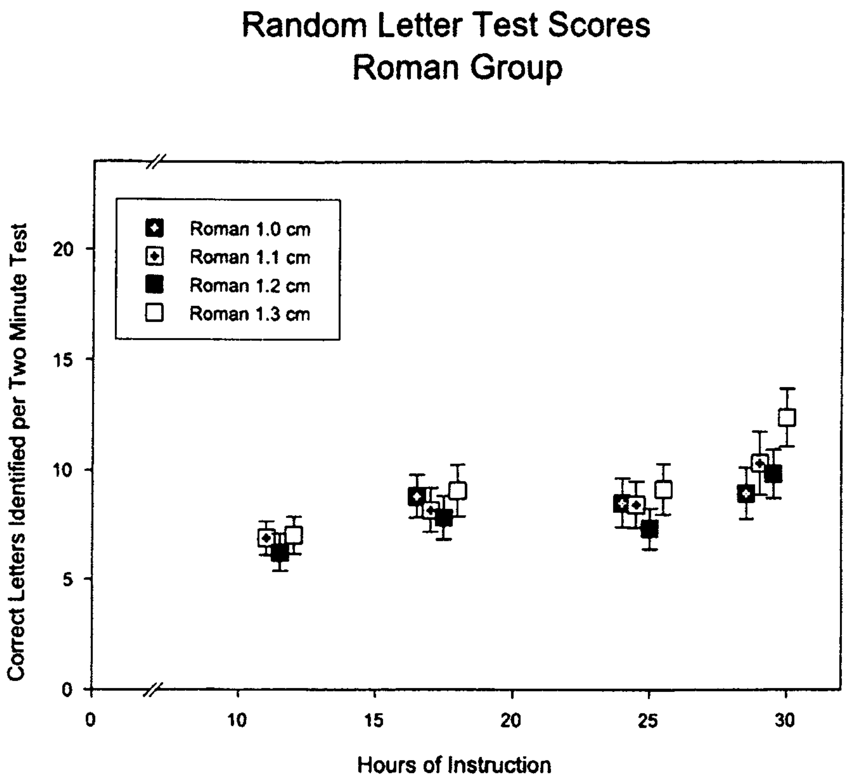
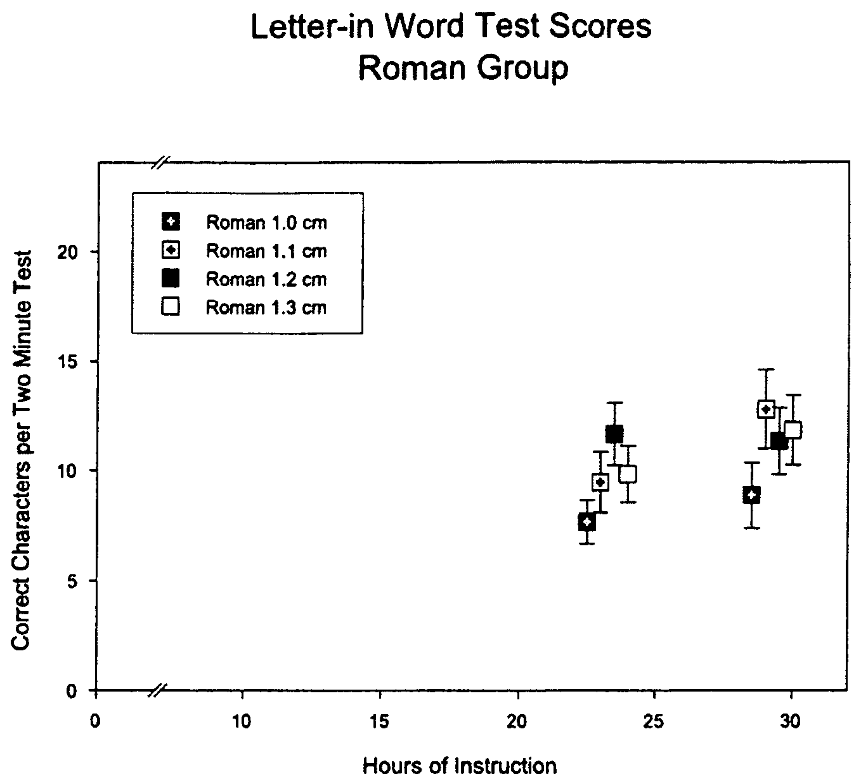


Fig. 1. Performance of the Roman alphabet group in terms of mean number of characters identified per two minute test on the four RL tests as a function of instruction time and font size. Results from four different font sizes are shown as different symbols including white squares (1.3 cm font), black squares (1.2 cm font), black crosses in white squares (1.1 cm font) and white crosses in black squares (1.0 cm font). For clarity, multiple data points obtained from a single experimental session have been slightly offset from one another. Error bars represent standard errors.

TABLE 6. Summary of the letters-in-words (LIW) test results from the Roman and ELIA groups. These LIW tests were administered one week apart.

	Roman		*ELIA*	
	Test LIW1	*Test LIW2*	*Test LIW1*	*Test LIW2*
Score				
1.0 cm	7.66	8.87	12.55	17.47
1.1 cm	9.47	12.79	14.38	20.12
1.2 cm	11.66	11.34	17.97	19.34
1.3 cm	9.84	11.84	13.28	18.28
Average	9.66	11.21	14.54	18.80
SD	7.98	9.88	12.56	12.88
Accuracy				
1.0 cm	57%	58%	71%	81%
1.1 cm	64%	70%	74%	84%
1.2 cm	71%	72%	86%	86%
1.3 cm	67%	73%	76%	86%
Average	65%	68%	77%	84%
SD	29%	33%	22%	18%
Speed				
1.0 cm	12.16	12.53	15.79	19.98
1.1 cm	12.87	15.66	17.21	22.81
1.2 cm	14.82	13.71	19.93	21.61
1.3 cm	12.29	14.55	16.03	20.66
Average	13.03	14.11	17.24	21.27
SD	7.13	8.74	11.73	12.14

Fig. 2. Performance of the Roman alphabet group in terms of mean number of characters identified per two-minute test on the two LIW tests as a function of instruction time and font size. Results from four different font sizes are shown as different symbols including white squares (1.3 cm font), black squares (1.2 cm font), black crosses in white squares (1.1 cm font) and white crosses in black squares (1.0 cm font). For clarity, multiple data points obtained from a single experimental session have been slightly offset from one another. Error bars represent standard errors.



group subjects were an average of 8% higher in the last LIW test (Test LIW2) than in the last RL test (Test RL4).

In terms of word per two minutes (wptm) reading speed in the final LIW test, 20 subjects (out of 38) in the Roman group were able to read and identify at least one whole word during final testing and two subjects were able to read more than 10 words in the final two-minute test. The wptm mean score for Test LIW2 across all font sizes was 2.17, with a range of 0 to 15 correct wptm.

ELIA GROUP

Random letter tests As illustrated in Figure 3, the scores of the ELIA group improved over the course of the study in the four font sizes in RL testing, although they varied widely. The average improvement by the group was 122%. Measures of speed and accuracy both showed improvement. The final score, speed, and accuracy scores ranged from 2 to 47, 4 to 47, and 50 to 100%, respectively, for 1.3-cm letters (Table 5). For 1.0-cm letters, the ranges were 0–55, 2–55 and 0–100% for score, speed, and accuracy, respectively. Results for tests using 1.3-cm letters were consistently higher in terms of score, speed, and accuracy than for tests using 1.0-cm letters, as was the case with the Roman Group. However, the ELIA group as a whole continued to show performance improvement across sessions with 1.0-cm characters.

Letters-in-words tests The ELIA group's average final LIW test scores are illustrated in Figure 4 and Table 5. Observed ranges for final scores,

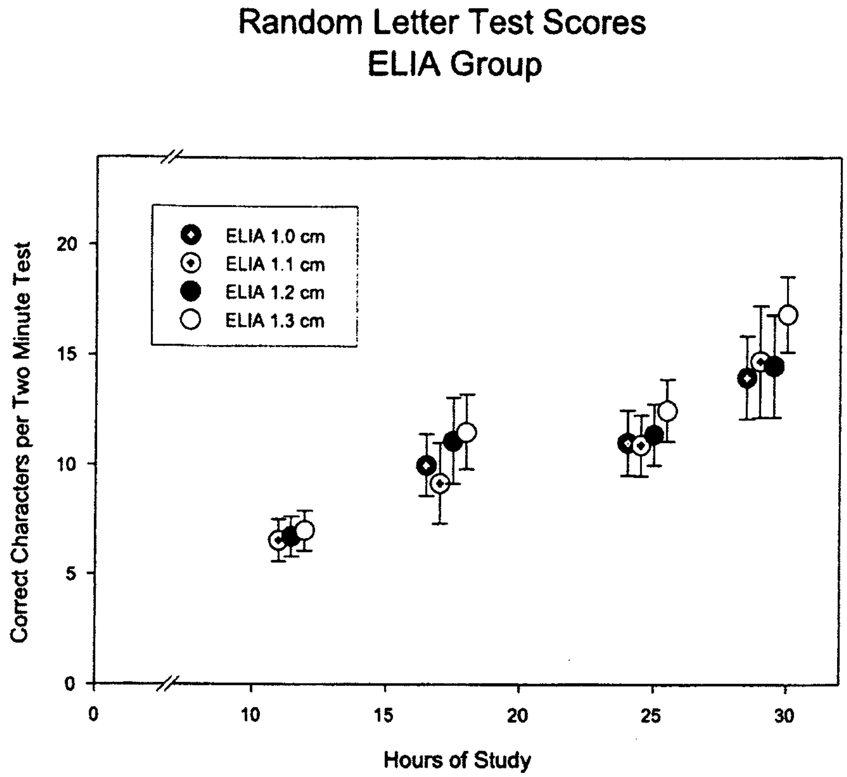


Fig. 3. Performance of the ELIA alphabet group in terms of mean number of characters identified per two minute test on the four RL tests as a function of instruction time and font size. Results from four different font sizes are shown as different symbols including white circles (1.3 cm font), black circles (1.2 cm font), black crosses in white circles (1.1 cm font) and white crosses in black circles (1.0 cm font). For clarity, multiple data points obtained from a single experimental session have been slightly offset from one another. Error bars represent standard errors.

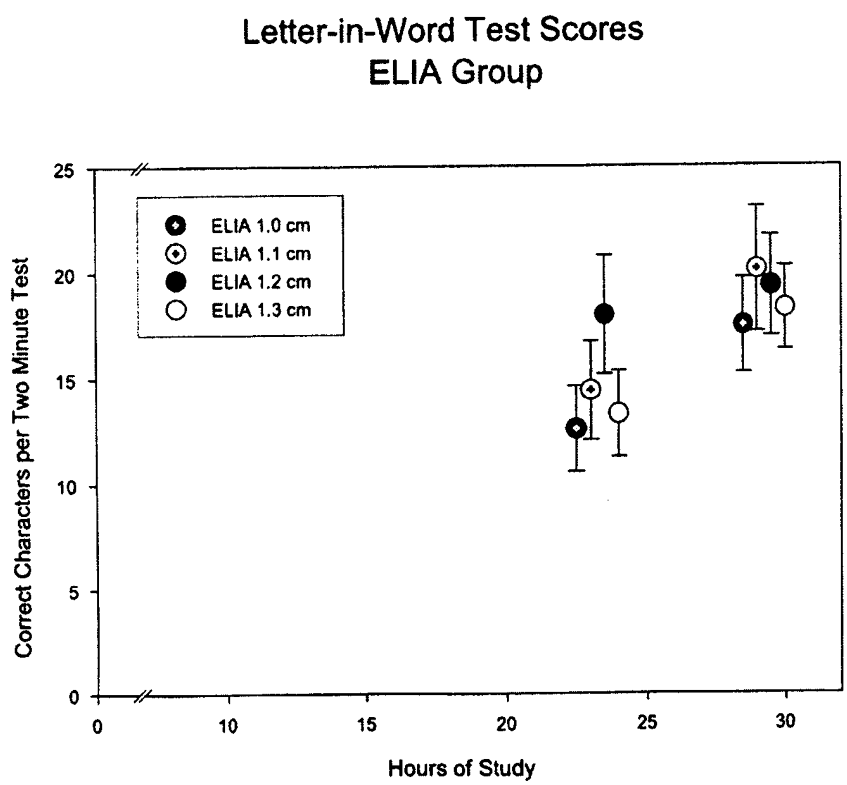


Fig. 4. Performance of the ELIA alphabet group in terms of mean number of characters identified per two minute test on the two LIW tests as a function of instruction time and font size. Results from four different font sizes are shown as different symbols including white circles (1.3 cm font), black circles (1.2 cm font), black crosses in white circles (1.1 cm font) and white crosses in black circles (1.0 cm font). For clarity, multiple data points obtained from a single experimental session have been slightly offset from one another. Error bars represent standard errors.

speed, and accuracy for the 1.3-cm font were 3–54, 4–54, and 64–100%, respectively, and for the 1.0-cm font 0–57, 2–57, and 0–100%, respectively. The ELIA subjects attempted to identify more letters in LIW tests (vs. RL tests) and they were more accurate identifying the letters they attempted. As a result, across the four font sizes, ELIA subjects tested on average 25% higher, in terms of score, on LIW tests than on RL tests.

In the final LIW test, 22 ELIA subjects (out of 29) were able to read and identify at least one complete word during final testing. The average wptm score was 3.91 (range: 0–20 wptm). Seven subjects were able to read ten or more words in one of their final LIW tests.

BRAILLE GROUP

Random letter tests The Braille subjects had difficulty learning standard Braille and, over the course of the study, did not learn the alphabet in its entirety. The group was taught and tested on the letters A through J by the tenth session (hour 15), A through P by the sixteenth session (hour 24), and A through U by session 20 (hour 30). As seen in Table 7, the subjects' overall score, speed, and accuracy in RL tests remained relatively constant throughout the study. As with the Roman and ELIA groups, in final RL testing there was a wide range of results with score, speed, and accuracy ranging from 0 to 25, 1 to 25, and 0 to 100%, respectively.

Letters-in-words tests All subjects had practiced identifying letters in standard-spaced Braille words in exercises. However, they had greater difficulty reading the letters in words when they were presented in standard Braille word spacing than when letters were presented randomly with greater spacing (as in RL Testing). As Figure 5 and Table 7 illustrate, the Braille group's performance declined substantially in LIW tests compared to RL tests. The subjects achieved an average score of 1.55 clptm (range: 0–11), speed of 5.35 laptm (range: 1–16), and accuracy of 20% (range: 0–80%). Twenty-seven of the 33 subjects read at 2 clptm or less in BLIW. The score, speed, and accuracy performance declines were 70%, 50%, and 23%, respectively, in BLIW vs. BRL3 test results, which were obtained during the same session.

TABLE 7. Summary the Braille group results. Data was collected from three RL tests on subsets of the alphabet: a through j (Test BRL1), a through p (Test BRL2), and a through u (Test BRL3), and from one LIW test on a subset of the alphabet: a through u (Test BLIW).

	Test BRL1 (a–j)	*Test BRL2 (a–p)*	*Test BRL3 (a–u)*	*Test BLIW1 (a–u)*
Score	6.79	6.72	5.16	1.55
SD	6.52	5.10	4.80	2.28
Speed	12.68	12.42	10.69	5.35
SD	6.61	4.43	4.76	3.85
Accuracy	47%	50%	43%	20%
SD	27%	27%	27%	25%

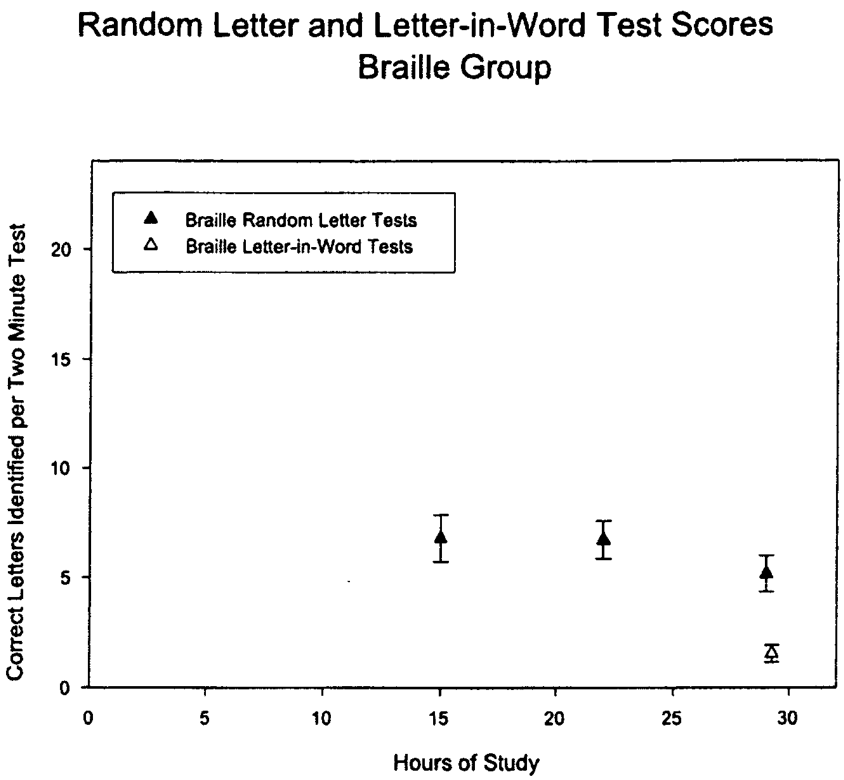


Fig. 5. Performance of the Braille alphabet group in terms of mean number of characters identified per two-minute test on three RL tests (black triangles) and one LIW test (white triangle) as a function of instruction time. Error bars represent standard errors.

In terms of correct words read per two minutes (wptm), one subject was able to read two words correctly in the LIW tests and two subjects were able to read one word correctly in the tests. The other thirty subjects were unable to read one word correctly in either test. The average wptm score for the LIW Braille tests was 0.08.

STATISTICAL COMPARISONS In order to ascertain whether the results of the three alphabet groups were significantly different from each other, the final test results of the ELIA, Roman, and Braille groups were compared. Since performance also varied with test type (RL vs. LIW), results were also compared across test types. Additionally, the final results of the ELIA and Roman tests at 1.3 cm and 1.0 cm were compared across font sizes to determine if font-size reductions affected the performances of the groups differently. Finally, results of the initial and final RL tests and initial and final LIW tests were compared for the effect of training for the ELIA and Roman groups only.

Effects of alphabet type Performance differences among the groups were evident for both RL and LIW test scores, as shown in Figures 6 and 7, respectively. A series of one-way ANOVAs were used to identify those conditions in which alphabet type had a significant effect, as shown in Table 8. The mean scores of the individual groups were then compared directly using a Scheffé test to determine the smallest significant difference between two group means. The performances of the

TABLE 8. Significance levels obtained from one-way analyses of variance (ANOVAs) applied to determine the effects of alphabet type on performance. Individual group means are compared pairwise (Elia/Roman; Elia/Braille; Roman/Braille) using a Scheffé test.

	Random-letter testing (Test RL4)				*Letters-in-words tests (Test LIW2)*			
	Alphabet type	*E/R*	*E/B*	*R/B*	*Alphabet type*	*E/R*	*E/B*	*R/B*
1.0 cm								
Score	0.001	0.05	0.001	NS	0.001	0.001	0.001	0.001
Speed	0.005	NS	0.005	NS	0.001	0.005	0.001	0.001
Accuracy	0.001	NS	0.001	0.025	0.001	0.01	0.001	0.001
1.1 cm								
Score	0.001	NS	0.001	NS	0.001	0.05	0.001	0.001
Speed	0.01	NS	0.01	NS	0.001	0.025	0.001	0.001
Accuracy	0.001	NS	0.001	0.001	0.001	NS	0.001	0.001
1.2 cm								
Score	0.001	NS	0.001	NS	0.001	0.005	0.001	0.001
Speed	0.01	NS	0.01	NS	0.001	0.005	0.001	0.001
Accuracy	0.001	NS	0.001	0.001	0.001	NS	0.001	0.001
1.3 cm								
Score	0.001	NS	0.001	0.001	0.001	0.01	0.001	0.001
Speed	0.001	NS	0.001	NS	0.001	0.01	0.001	0.001
Accuracy	0.001	NS	0.001	0.001	0.001	NS	0.001	0.001

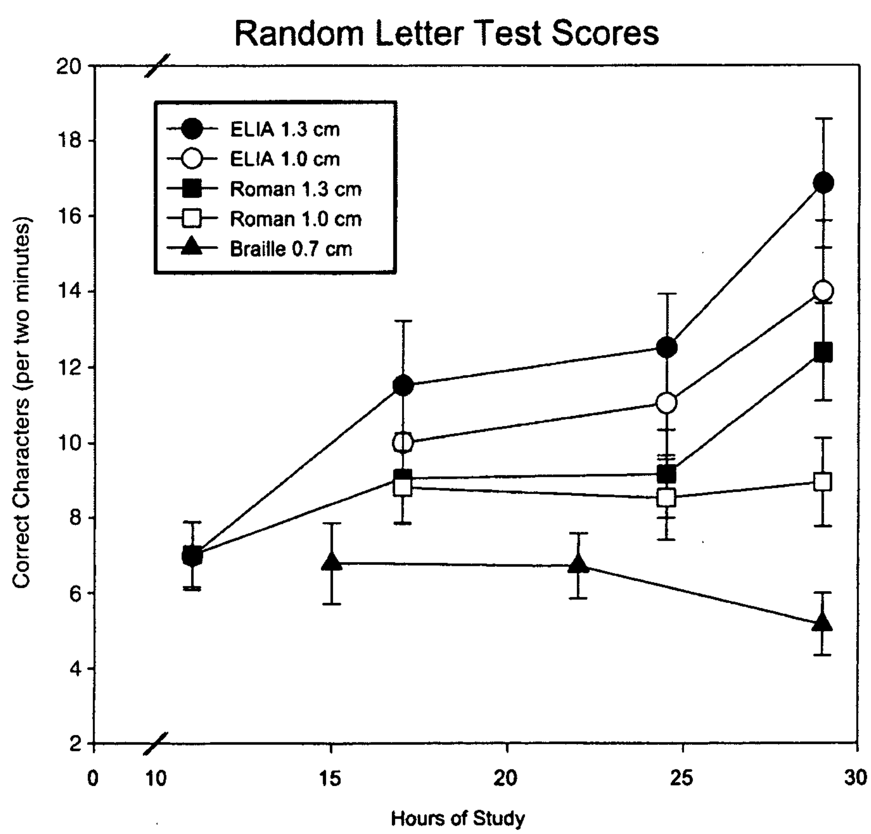


Fig. 6. Performance of the three groups in terms of mean number of characters identified per two-minute test on the RL tests as a function of instruction time. For the Roman alphabet group, results from the 1.3 cm font size are shown as black squares, and results from the 1.0 cm font size are shown as white squares. For the ELIA alphabet group, results from the 1.3 cm font size are shown as black circles, and results from the 1.0 cm font size are shown as white circles. Results from the Braille group are shown as black triangles. Error bars represent standard errors.

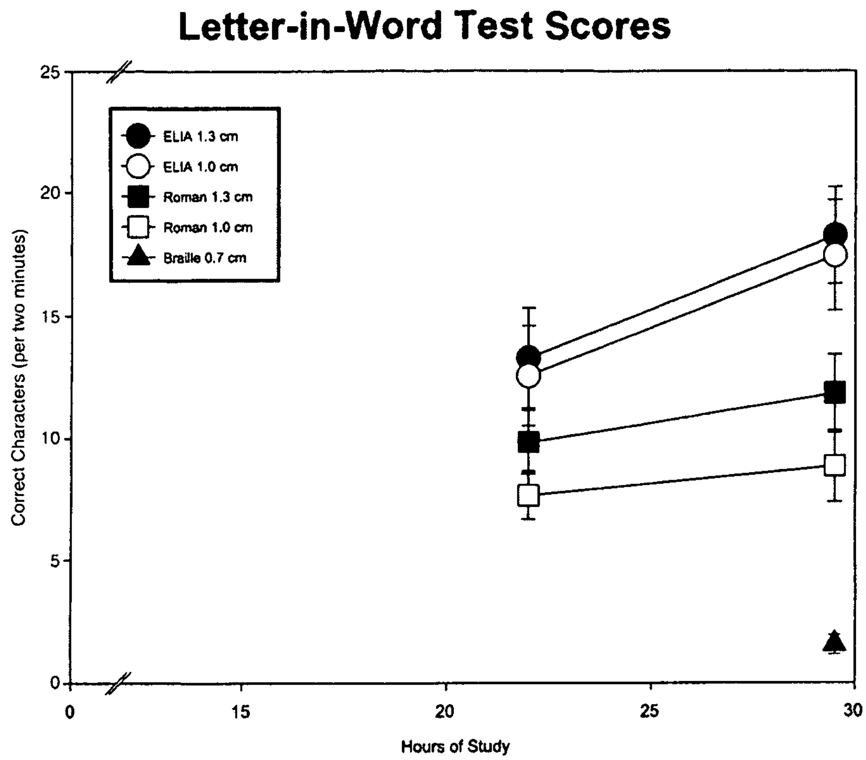


Fig. 7. Performance of the three groups in terms of mean number of characters identified per two-minute test on the LIW tests as a function of instruction time. For the Roman alphabet group, results from the 1.3 cm font size are shown as black squares, and results from the 1.0 cm font size are shown as white squares. For the ELIA alphabet group, results from the 1.3 cm font size are shown as black circles, and results from the 1.0 cm font size are shown as white circles. Results from the Braille group are shown as a black triangle. Error bars represent standard errors.

ELIA and Braille groups were found to be significantly different from one another across both RL and LIW tests and all font sizes in terms of score, speed, and accuracy ($p < 0.01$ for all comparisons). However, the ELIA/Roman and Roman/Braille comparisons did not yield the same high levels of significance. For example, in the ELIA/Roman RL test comparisons, the two groups were only found to be different with respect to score ($p < 0.05$) for the smallest size (1.0 cm), while the performances of the two groups were found to be significantly different in LIW tests in score ($p < 0.05$) and speed ($p < 0.025$) for all four font sizes and in accuracy for the smallest font size ($p < 0.01$). Similar disparities were found in the Roman/Braille comparisons. In RL testing, the higher performance of the Roman group over the Braille group was only found to be significant with respect to accuracy ($p < 0.025$) for all font size comparisons and for the largest font size (1.3 cm) with respect to score ($p < 0.001$). The performance differences between the Roman and Braille groups were, however, very clear in the LIW tests, with the scores, speeds, and accuracies all found to be significantly different in all font-size comparisons ($p < 0.01$).

Effects of test type Apparently, presenting letters closer together and within the context of words had a positive effect on the performance of the ELIA and Roman groups and the opposite effect on the performance of the Braille group. As shown in Table 8, comparing the differences between the three sets of LIW/RL results, there was an effect of alphabet type when comparing the ELIA, Roman, and Braille groups (at all font sizes) in terms of score, speed, and accuracy. A series

of 2-way ANOVAs were used to compare the effects of test type and to identify any interactions between test type and alphabet at multiple font sizes, the results of which are summarized in Table 9. In general, significant effects of test type and interactions between test type and alphabet were observed for the ELIA/Braille and Roman/Braille group comparisons.

Effects of font size It was also found that font size affected the performances of the ELIA and Roman groups in final testing. The results obtained from the ELIA and Roman groups were most different when the letters were closely spaced (as with LIW tests) and presented at the smallest font sizes (see Figure 7). Conversely, the Roman/Braille comparisons were most different when the letters were closely spaced and the Roman alphabet was presented at its largest font. Comparing the 1.3-cm tests to the 1.0-cm tests of the two groups yielded significant differences in terms of accuracy in both RL tests ($p < 0.001$) and LIW tests ($p < 0.05$). However, score and speed declines were not significant. Also, when comparing the ELIA and Roman groups, there was an effect of alphabet type, in both the RL and LIW tests, on score ($p < 0.005$ and $p < 0.001$, respectively), speed ($p < 0.01$ and $p < 0.001$, respectively), and accuracy ($p < 0.005$ and $p < 0.001$, respectively).

Effects of training The effect of training on the ELIA and Roman groups was examined by comparing the performance improvements of these groups from Tests RL1 to RL4 (see Figure 6) and from Tests LIW1 to LIW2 (see Figure 7). In RL testing, it was found that there was an effect of training ($p < 0.01$) in all performance measures (score, speed, and accuracy) for all tested font sizes (1.0 cm was not tested in Test RL1). Tests LIW1 and LIW2 were administered one week apart and the results were also compared; there was a significant effect of

TABLE 9. Significance levels obtained from two-way analyses of variance (ANOVAs) applied to determine the joint effects of alphabet type and test type on performance at different font sizes.

	1.0 cm			*1.1 cm*			*1.2 cm*			*1.3 cm*		
	E/R	*E/B*	*R/B*	*E/R*	*E/B*	*R/B*	*E/R*	*E/B*	*R/B*	*E/R*	*E/B*	*R/B*
Score												
Alphabet effect	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.001	0.001
Test-type effect	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	0.025	NS	NS	0.025	0.025	NS	0.025	0.025	NS	NS	NS
Speed												
Alphabet effect	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Test-type effect	NS	NS	0.005	NS	NS	0.025	NS	NS	0.025	NS	NS	0.025
Interaction	NS	0.01	0.025	NS	0.005	0.025	NS	0.005	0.025	NS	0.025	0.05
Accuracy												
Alphabet effect	0.001	0.001	0.001	0.025	0.001	0.001	0.025	0.001	0.001	0.01	0.001	0.001
Test-type effect	NS	0.05	0.025	NS	0.05	NS	NS	0.05	NS	NS	0.005	0.01
Interaction	NS	0.01	0.025	NS	0.001	0.005	NS	0.001	0.025	NS	0.005	0.05

training on speed ($p < 0.05$) with the 1.3-cm font only. Presumably, the effect of training was muted by the limited time between the two LIW tests.

Discussion This preliminary study of 100 blindfolded adults focused on evaluating three fonts: the ELIA alphabet, the Roman alphabet, and Braille in order to assess their potential for use by adventitiously blinded seniors. The results indicate that elderly print readers can learn and use tactile fonts. The results also indicate that seniors, after 30 hours of instruction, study, and testing, could read the ELIA alphabet faster and more accurately than the raised Roman alphabet and that the seniors could read the raised Roman alphabet faster and more accurately than standard-size Braille. Furthermore, test type and font size affected both the speed and accuracy with which subjects identified letters.

One goal of this study was to ascertain what presentations of tactile fonts might offer the greatest utility to newly blinded senior tactile readers. For readers to utilize a tactile alphabet, they must be able to identify its letters accurately. The utility of an alphabet is also dependent on the speed with which readers can identify characters. Furthermore, the rate at which the performance of readers improves is likely to influence their continuing motivation to master the alphabet and the interim utility of the alphabet. Reading rates and accuracy levels dictate the final utility of a given alphabet and are the ultimate measure of the tangibility of an alphabet (defined as the capacity of a character to be correctly discerned by touch).

Roughly 25% of the seniors who initially expressed an interest in this study lacked the tactile acuity, literacy, motivation, or sustained good health for inclusion in, or completion of, the five-week course. The inclusion criteria and completion requirements were necessarily strict in order to ensure standardization across the three treatment groups, but are not necessarily good indicators for what portion of the senior population would be likely candidates for tactile alphabet training. It is possible that the proportion of visually impaired learners that could successfully complete a similar course would be higher, as the visually impaired learners may be more motivated to learn a tactile alphabet. Visually impaired learners may also rely on, and acquire, general tactile skills to compensate for their lack of vision and may therefore enjoy greater success in reading tactile texts. Conversely, a number of the subjects in each group had no success in reading tactile texts, and so it is possible that greater tactile acuity than the minimum inclusion criteria for this study is needed for successfully reading tactile text, or, that larger font sizes would need to be available for those with poor tactile ability. No blind subjects were included within the three experimental groups, as their prior exposure to tactile alphabets and tactile exploration, and their motivation may have differed greatly from their sighted classmates.

Size and letter spacing are two factors that also affect the utility and tangibility of a tactile alphabet. The tangibility of letters in the alphabet at a small size and with limited space between letters affects the reading utility of the alphabet both in terms of utility to the user and

the economics of producing materials for the users. Larger letters, even widely spaced, that can be identified quickly and accurately have greater utility than smaller letters, closely spaced, that are slow to identify and cannot be accurately identified. This point is especially relevant when addressing the needs of visually impaired seniors who may have less tactile acuity[5] and are likely to use a tactile alphabet primarily for labeling, note taking, and limited reading, because the greatest impact a tactile alphabet can have on these readers is in assisting them to complete basic daily activities independently.[18]

While the study's duration was not such that learning curves and terminal reading speeds could be ascertained for each of the alphabets, the results from this study can be compared with a published case study[3] of previously sighted 'late blindness' Braille readers. Millar[3] reported that, in a study of Braille readers who had learned Braille as adults, the five subjects averaged a reading speed of 24 wpm (range: 15–37 wpm). The subjects had been reading Braille for 4–11 years after reading print for more than 40 years. Given these likely asymptotic reading speeds and the difficulty experienced by the Braille group (in final LIW tests, 27 of the 33 subjects correctly read two letters per two minutes or less), standard Braille presents a substantial challenge for most seniors. Other alphabets, such as the ELIA and Roman alphabets, which showed significantly higher character and word recognition speeds, may offer greater utility for seniors.

Practically, the results suggest that 30 hours of study are not sufficient for new senior tactile readers to achieve extended text reading speeds. Roughly 80% of Braille readers currently use Braille primarily for labeling and note taking, while they prefer other means for reading extended text (e.g., text-to-speech or audiotape).[19] Nevertheless, Braille is credited as a key factor in Braille readers' continued independence.[20] In light of this, a more realistic goal for most new senior tactile readers would be to use tactile labels and notes for those activities for which Braille is most often used, i.e., to independently complete essential daily living tasks. Additional practice with the alphabets would certainly be needed to achieve desirable extended text-reading speeds, and for some seniors such speeds may not be achievable. In terms of reading labels, subjects in the study were able to read and identify single words and could likely do so with labels, if they could achieve a high level of accuracy. In terms of brief notes or short texts, Legge has demonstrated that reading speeds of 10 wpm were sufficient for reading comprehension.[21] Data from the present study showed that many of the subjects were able to approach this speed within the short study period.

In order to identify factors that influence the tangibility of an alphabet, and therefore its potential utility, we studied two different presentations: individual letters widely spaced and letters closely spaced within the context of words. Studying the identification of letters closely spaced versus letters within words is useful in understanding the tangibility of letters in reading tasks. The presentation of letters widely spaced or individually is not indicative of the tangibility of the letters in reading tasks; it is, however, essential in ascertaining the general tangibility of the individual characters of an alphabet. Both measures of

tangibility were targeted in this study in an attempt to gauge the practical utility of learning the three fonts.

A third approach to reading efficiency takes into account a subject's ability to accurately navigate a page of text. In studies of this type, it is customary to include characters missed due to 'tracking errors'. It has been noted above that tracking errors were excluded from our analysis. The inclusion of these missed characters would have had no effect on our measures of score (numbers of correct letters identified would remain unchanged), but would have artificially increased speed (letters attempted) in a way that was not meaningful and would have reduced accuracy rates proportionately. If these missed characters had been included, the average accuracy rates from tests RL4 and LIW2 would have been 2%, 11%, and 1% lower for the ELIA, Roman, and Braille groups, respectively. Lest the reader attribute any undue significance to these numbers, it should be noted that the majority of tracking errors occurs during the transition from the end of one line of text to the beginning of another (after every 10–12 characters in the test materials). Under our testing methodology, slower readers could be expected to have fewer tracking errors. Furthermore, tracking errors were not equally distributed across the subjects of any given group, as most errors were committed by a small number of subjects.

The performance differences of the three fonts were most pronounced in LIW Tests, where practical reading tasks were studied and the letters were more closely spaced. In RL testing, with letters widely spaced, the ELIA and Braille groups were also found to be significantly different in terms of score, speed, and accuracy for all font-size comparisons, as shown in Tables 5 and 7. However, the differences in the ELIA/Roman and Roman/Braille performance comparisons were less pronounced in RL testing.

It is evident that as font size and spacing were reduced, the fonts were not equally affected. For example, when the fonts were presented in LIW tests and at smaller font sizes, their performances were most different. Conversely, a comparison of the results of the widely spaced RL tests and larger size tests showed smaller differences between the fonts. Furthermore, the differences between the Roman alphabet and standard-size Braille narrowed when the Roman alphabet was presented at the smallest size. This may have occurred because the physical spacing (crowding) of the elements in the Roman letters approached the point where subjects could no longer resolve individual features. Alternatively, this effect may occur because internal and peripheral clutter from letter elements and other adjacent letters is least apparent with large letters and letters widely spaced, and more apparent with smaller letters closely spaced.

Larger Braille font sizes, such as Jumbo Braille, may hold promise for older readers as larger letters may be easier to tactilely differentiate; they could not, however, be tested within the confines of this study. It is also possible that some of the observed difficulty of the Braille group may be found at all sizes, as Braille may be more susceptible to lateral masking, at least with respect to former print readers. Former fluent print readers are accustomed to thinking of letters in terms of outline shapes,[3] because outline shapes provide anchor points to which

exploratory movements can be related.[22] Braille letters' design, in which varied amounts of space, not outline borders, denote the beginning and end of letters may therefore cause problems for former print readers at all font sizes.

Several tactile alphabets that have been designed for the blind were not studied. The best-known tactile alphabet alternative to Braille is the Moon alphabet. In 1845, Dr. William Moon of East Sussex, England, designed the Moon alphabet for the blind. Its symbols have simple shapes that are in many cases similar to those of the Roman alphabet.[3] It was originally produced by using 14 different shaped copper bands that, when rotated and pressed into paper, could produce tactile text that was readable by the previously sighted. Moon's production means was more efficient than using standard Roman letters but more cumbersome than Braille. It is believed that Moon was used less than Braille primarily because in the 1800s blind users could not use available technology to produce Moon tactile text themselves, whereas they could produce their own tactile text with Braille.

Moon is presently used on only a limited basis in the United Kingdom, and is favored by fewer people than Braille. As Moon and other tactile alphabets have not been shown to be superior to the Roman or Braille alphabets and the researchers had limited resources with which to conduct this study, these additional tactile alphabets were not explored. Also, Moon was designed around the technology available in the 1800s (as was Braille). As such, it may not leverage current technology to its utmost to best serve the blind, in that a larger array of shapes can now be produced and Moon may not be the most efficient method available.

The ELIA and Roman groups appear to have benefited from the spacing and context of the LIW tests, while the Braille group suffered significant declines in accuracy and recognition speed in these tests. As context is generally recognized as a factor that would improve reading performance, and as the Braille group had exposure to letters in words in their exercises, the 2.0-mm standard spacing of the letters in the Braille test is the probable reason for the decline in the performance of the Braille group. This finding is compatible with the findings of Pester et al.[12] and Nolan and Kederis,[2] who found that additional space between Braille letters improves accuracy. It is also possible that presenting characters as parts of whole words only improves speed and accuracy of recognition after letter identification has reached some minimum level of performance. This performance may be when subjects are able to use pattern-matching heuristics for overall letter shape rather than relying on deductive reasoning, and that the subjects in this experiment had not attained that level of expertise.

Previous studies found a superior tangibility of Braille over a raised Roman alphabet. The present study does not contradict those studies, as its subjects and text presentation were different. For example, Loomis[23] found that Braille was superior to Roman fonts in tactile and filtered or blurred visual recognition tasks. That study examined pattern recognition with subjects who had learned the Braille alphabet visually without instruction, who were able to identify the Braille letters visually with 100% accuracy, and who were presented with single

isolated letters. However, the letters were presented statically or with restricted finger movement and with limited stimulus exposure times. Additionally, the Roman letters were smaller than in the present study, comparable in size to Braille, and were of a different font design.

The finding of our study that the use of frames in the ELIA font may improve tactile recognition rates is not at odds with previous studies on the use of frames in tactile recognition tasks. Loomis[24] and Millar[3] both studied the recognition of Braille letters that had frames surrounding them, and found that frames hampered the ability of subjects to distinguish Braille letters. However, while Braille symbols with a surround may be less tangible than standard Braille, the results in the Loomis study[24] show that those Braille letters with the greatest amount of space between the interior element and the exterior frame were the most discernable of the framed symbols, i.e. the shape of the frame and its relation to the interior elements may influence the perception of the whole character. The present study constitutes a preliminary step in assessing the usefulness of tactile fonts to those older adults who suffer from a severe loss of vision. It should be noted that the purpose of this research was not to offer ELIA or any Roman-based tactile font as an alternative tactile alphabet for Braille readers. The ELIA and Roman fonts were explored as choices for newly visually impaired elderly persons who do not already know Braille. There are a number of limitations to the current study, including the fact that the subjects had functional vision but were blindfolded, the use of residual vision was not permitted, and the subjects were not permitted to study outside the classroom sessions. In addition, future studies might benefit from including experienced Braille users among the subjects, and long-term learning curves might be obtained from a number of subjects to investigate the time and course of study for learning the tactile skills, as well as an estimate of asymptotic performance. This research does, however, suggest that, within the resources that our present rehabilitation system has to offer, standard Braille may not be an optimum training tool for all newly blinded seniors as it presents challenges that the elderly find difficult to surmount. Senior visually impaired persons may, however, benefit from the use of tactile alphabets closely related to the Roman alphabet, such as the ELIA alphabet and the raised Roman font tested in this study. Since tactile fonts can promote independence, and as they have been found to be learnable, new tactile fonts can be made available for those who are not currently reading Braille.

References

1 Goble AK, Collins AA, Cholewiak RW. Vibrotactile threshold in young and old observers: the effects of spatial summation and the presence of a rigid surround. *J Acoust Soc Am.* 1996;99(4):2256–2269.

2 Nolan CY, Kederis CJ. *Perceptual factors in Braille word recognition.* New York, NY: American Foundation for the Blind, 1969.

3 Millar S. *Reading by touch.* London: Routledge, 1997.

4 Stevens J, Choo K. Spatial acuity of the body surface over the life span. *Somatosens Mot Res.* 1996;13(2): 153–166.

5 Stevens J, Foulke E, Patterson M. Tactile acuity, aging, and Braille reading in long term blindness. *J Exp Psychol Appl.* 1996;2:91–106.

6 Stevens J, Patterson M. Dimensions of spatial acuity in the touch senses over the life span. *Somatosens Mot Res*. 1995,12(1):29–47.
7 McNeil JM. *Americans with disabilities: 1994–1995. Data from the survey of income and program participation*. Washington, DC: U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census, 1996.
8 Russell JN, Hendershot GE, LeClere F, Howie LJ, Adler M. *Trends and differential use of assistive technology devices: United States, 1994. Advance data from vital and health statistics; no. 292*. Hyattsville, MD: National Center for Health Statistics, 1997.
9 Heller MA, Schiff W, editors. *The psychology of touch*. Hillsdale, NJ: Lawrence Erlbaum Associates, 1991.
10 Gray WS, Robinson HM. *Gray oral reading test*. Indianapolis, IN: Bobbs-Merrill, 1967.
11 Chepaitis EV. ELIA ™: a simpler tactile code for persons with visual impairment. *J Visual Impair Blind*. 1996;90(3):282–283.
12 Pester E, Petrosko J, Poppe K. Optimum size and spacing for blind adults to the Braille code. *Re:view*. 1994;26(1):15–22.
13 Caton H, Gordon B, Roderick C, Pester E, Modaressi B. *The Braille connection*. Louisville, KY: American Printing House for the Blind, 1997.
14 Pester E. *Read again*. Louisville, KY: American Printing House for the Blind, 1990.
15 Holbrook MC, Koenig AJ. Teaching braille reading to students with low vision. *J Visual Impair Blind*. 1992;86(1):44–47.
16 Erin J, Sumranveth P. Teaching reading to students who are adventitiously blind. *Re:view*. 1995;27(3):103–111.
17 Legge GE, Ross SJ, Luebker A. Psychophysics of reading VIII. The Minnesota low vision reading test. *Optom Vision Sci*. 1989;66:843–851.
18 Pester E. Braille instruction for individuals who are blind adventitiously: scheduling, expectations, and reading interests. *Re:view*. 1993;25(2):183–187.
19 Mack C. How useful is Braille? Reports of blind adults. *J Visual Impair Blind*. 1984;78:311–313.
20 Nemeth A. Braille: the agony and the ecstasy. *Braille Monit*. 1988; 31(5):July:316–324.
21 Legge GE, Ross JA, Maxwell KT, Luebker A. Psychophysics of reading VII. Comprehension in normal and low vision. *Clin Vision Sci*. 1989;4:51–60.
22 Millar S. *Understanding and representing space, theory and evidence from studies with blind and sighted children*. Oxford: Clarendon Press, 1994.
23 Loomis JM. On the tangibility of letters and Braille. *Percept Psychophys*. 1981;29(1):37–46.
24 Loomis JM. A model of character recognition and legibility. *J Exp Psychol Hum Percept Perform*. 1992;16(1):106–120.
25 O'Connell WF, Chepaitis AJ, Griffiths AF, Wyatt H. Evaluation of a new tactile alphabet for adventitiously blinded people over 65. Poster presented at the annual meeting of the American Academy of Optometry in Philadelphia, PA, 2001.
26 Chepaitis AJ, Griffiths AF, Wyatt H, O'Connell WF. Testing the ability of seniors to learn and read tactile alphabets. In: Matthews J, editor. Proceedings of the 2003 Investigative Ophthalmology and Visual Science Conference, Fort Lauderdale, FL, 2003; May 4–9; 44: E-Abstract 1290.